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ABSTRACT

This publication was designed to serve as a teacher's handbook for a four week "shop" adventure in elementary electricity for 12- or 13-year-old boys who would ordinarily not take an interest in electrical things. These projects could easily be adapted to aid any elementary physics treatment of electronics. Projects were designed to meet two main conditions: (1) to operate from D-cells or other safe, low-voltage sources, and (2) to be inexpensive enough (usually under $2.00 apiece) that they can be taken home for further play and investigation. Projects involve students in such aspects of electronics as magnets, electrostatics, circuits, electromagnets, electric motors, sound, and optics. Those projects were designed to be done usually one each five hour day but could be worked on in one or two hour lab sessions. Equipment and supplies lists are also included, along with pictures of the projects, teaching suggestions, suppliers list, and construction procedures. (MR)

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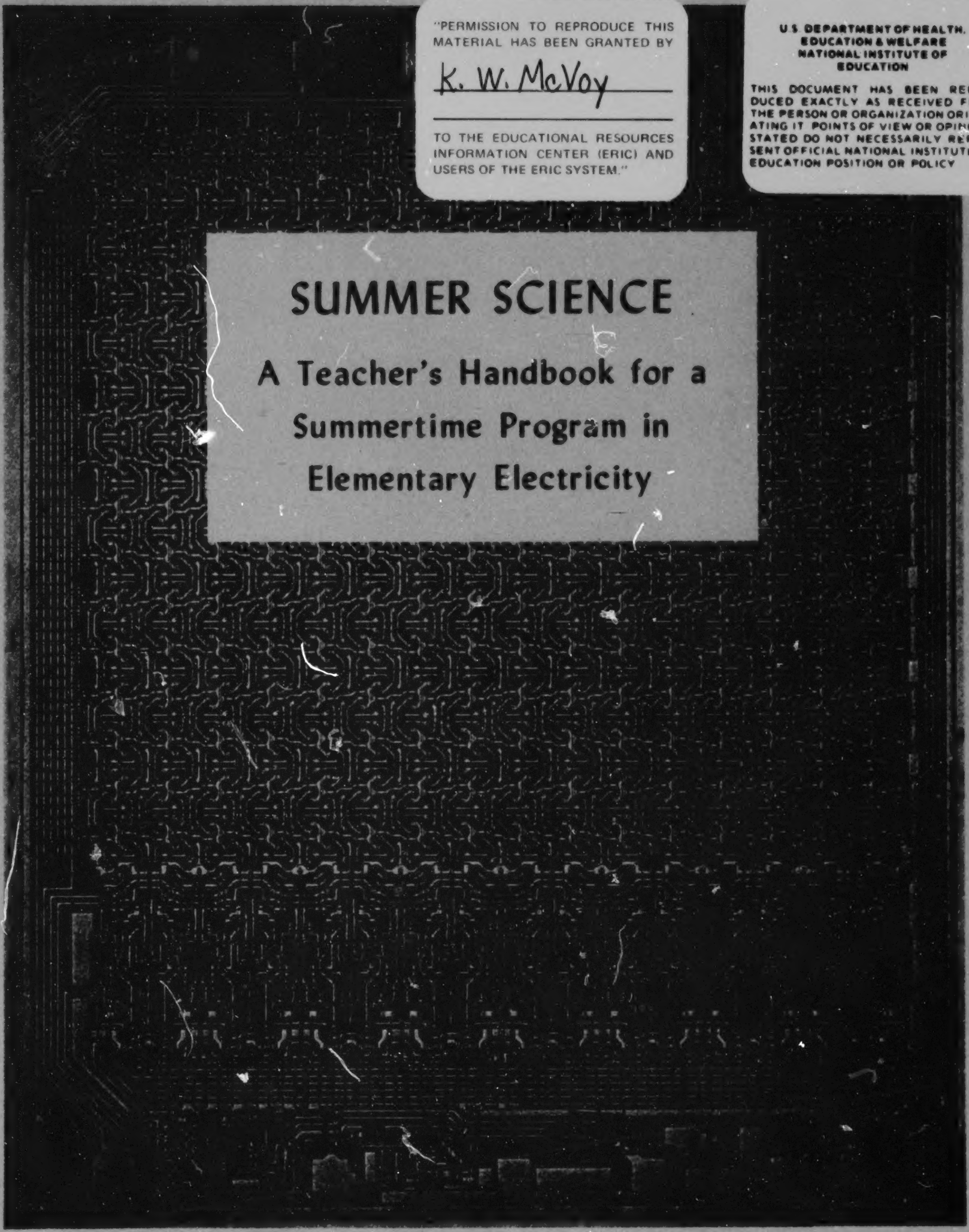

SUMMER SCIENCE

A Teacher's Handbook for a Summertime Program in Elementary Electricity

Distributed by the Department of Physics, The University of Wisconsin, Madison, Wisconsin 53706, under the joint auspices of the U.S. Office of Economic Opportunity and the Wisconsin Alumni Research Foundation.

The device pictured on the front cover is an "integrated circuit", produced by Fairchild Semiconductor as part of the high-speed memory circuit for the Illiac-4 computer at the University of Illinois. It contains 1244 transistors, 1170 resistors and 71 diodes, and because of the complexity of its layout, was designed entirely by computer. The magnitude of this accomplishment becomes apparent only when one realizes that the photograph is a 60 X enlargement; the entire circuit is actually this size: ■

SUMMER SCIENCE TEACHER'S HANDBOOK

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Summer Science is a month-long program of adventure in elementary electricity, designed to catch the fancy of junior high school boys; it was conceived primarily for boys who would not otherwise taste this type of excitement. The world knows many such boys, youngsters of considerable talent whose abilities as technicians and engineers are sorely needed by their home communities, but who at present are not pursuing these careers for lack of motivation or opportunity. The all-essential spark of enthusiasm needed to launch a career of this complexity can only be kindled by a sympathetic friend and teacher. Such a teacher will need a continuous supply of simple but intriguing circuits to feed the flame of excitement once it is ignited, and hopefully this handbook may serve as his woodpile.

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INTRODUCTION

The elementary-electricity projects collected together here are intended for the use of 12- or 13-year-old boys. They are designed specifically to appeal to boys who ordinarily would not take an interest in things electrical, and in consequence they are "projects", of the Electronics Illustrated type, rather than "experiments" of the Elementary Physical Science Course variety. The purpose of the collection is to encourage experimentation with elementary electrical devices and circuits, and as such it might be viewed as a practical summertime supplement to the usual junior high school science courses. Although this particular collection was generated in a rural context (a Chippewa Indian Reservation in Wisconsin), there is no reason why the projects described here should not be equally interesting to urban children.

The projects were designed with two main conditions in mind: that they operate from D-cells or similar safe and inexpensive low-voltage sources, and that they be cheap enough (generally under $2 apiece) that they can be given to the boys to take home for further play.

The handbook itself is not intended as a lab manual but merely as a guide and time-saver for anyone interested in organizing such a summer electricity course. Since it is not a textbook, space has been saved by skipping detailed explanations of the principles on which the projects are based; at least one of the teachers of the program must have training equivalent to that of a high school or college physics teacher, and the explanations will be obvious to him, anyway. The main purpose of the handbook is to make the organization of the program as painless as possible by providing a complete list (down to the pins and thumbtacks) of the components necessary for each project, together with the names and addresses of suppliers from whom they can be obtained, as well as an indication of the price. What distinguishes this compilation from the usual school science-supplies catalogues is that in every instance the cheapest possible components have been sought out, thereby permitting the same amount of money to buy many more projects.

Enough projects have been included to fill about 17 five-hour days (9-3, with an hour for lunch). This makes a four-week program, with three free days. If the purpose of the program is to encourage an interest in electricity or electronics as a possible career for the boys, it is extremely helpful to use these three days (or more) for "field trips" to nearby factories, research laboratories, military installations, etc. where the boys can see the same components they have been using put to practical use. One trip early in the second week and another late in the third week seems to work out well.

The project is likely to be more successful with a small group of boys than with a large one, since these boys will presumably have had no previous experience with electricity, and will appreciate as much individual attention and encouragement as possible. It is in essence a "shop course", and since the boys must have complete freedom to roam through the shop in search of tools and parts, about 20 boys should be an upper limit, and 10 is by no means too small. Unless they are very carefully selected in advance (for instance, by some type of competition in school the previous spring), it is a good idea to indicate at the beginning that the program is really designed for, say, only 3 weeks, with the possibility of an extra week of more advanced work for the more ambitious boys. This will provide an opportunity to give these boys more individual attention. Especially if a few difficult projects are tried late in the third week, the boys can probably be allowed to do this selecting themselves. Of course, those who leave after 3 weeks should be given their tool boxes to take home at that time, which in itself is something of an inducement to retire.

The summer between 8th and 9th grade seems an excellent age for the boys. If possible, they should all be in the same grade to avoid a wide spread in abilities and interests. Unless their community is too widespread for them to be bussed daily to a central school, CAP building, etc., it would be by far the best for them to live at home, and each day take home a newly-completed project to be exhibited and explained to parents and friends. Because the projects are too delicate to be exposed to the mercies of younger brothers, dogs, etc., it is essential that the boys be given large, sturdy storage boxes, with a lock, in which to keep their projects and tools safe at home. These boxes should be prepared before the course begins.

Ideally the teaching team would include a professor from the physics or electrical engineering department of a college or university. Second, in order to coordinate the work as closely as possible with the boys' schoolwork, it would be an excellent idea to incorporate a physics or electronics teacher from their own high school. Not only could he help with the selection of the boys for the course, but after it is over he could help them organize a "science club" to encourage further work along these same lines. For 20 boys, the total teaching staff should be about five. An excellent choice for the remaining three, if they are available, would be high school or college students from the same community as the boys taking the "course", provided that these students know enough practical electricity to understand the projects and assist the younger boys. If the program is repeated for several years, eventually its own "graduates" will make perfect members of the teaching staff for future programs.

As for ordering supplies, the orders should not be placed later than three months before the beginning of the program. Most suppliers will need at least three weeks to obtain the components in the quantities needed, and another two weeks should be allowed for shipment to many parts of the country. In some cases the component may have been discontinued, so that it will have to be tracked down from an alternative supplier. And finally, although all the projects described here have actually been built and tested with exactly the components listed, every teacher of such a program should definitely plan to build each project himself, well in advance of the course, to be certain he understands how it works and he has all the special tools necessary for it.

By far the simplest way of explaining just how a project is to be built is to provide the boys with a completed, operating model (marked MODEL for identification). It should be sturdily built, for they will copy it exactly, carrying it back and forth across the room for comparison, so that by the end of the day it may be fairly dog-eared. Incidentally, since some components are bound to be defective, and a few will surely be lost or broken, two or three more units than the boys will need should be purchased in every case. The prices quoted are as of summer 1969, and will probably increase

5% per year. No sales tax has been included, nor have shipping charges.

Incidentally, the total amount of equipment and supplies needed for 20 boys is quite large, probably enough to fill a 4' x 7' x 5' trailer, and it would arouse far too much curiosity and temptation to leave it exposed to the view of the boys during the course. If at all possible, it should be stored in a separate room, adjacent to the workroom in which the program is held, and should be under lock and key at all times.

Although formal lectures would surely be out of place, it will be necessary to assemble the boys briefly at the beginning of each new project to explain how it is to be built. They will get the most long-term benefit from each project if they carefully draw out its schematic wiring diagram first, and paste it permanently on the completed device. In addition it is very helpful to have them make an actual sketch of the model before beginning the building; as in any shop course, the temptation to "horse around" is ever-present, and the enforced silence of a few minutes of sketching is invaluable for establishing a quiet atmosphere in the room. At the same time, boys of this age are an exuberant bunch, who must be allowed morning and afternoon recess breaks to work off excess energy. Swimming is ideal if possible, as are baseball and basketball. The Chippewa boys happened to be great horseshoe enthusiasts, and the ever-present horseshoes just outside the door were so useful as a pastime for the boys who finished projects early, that I would suggest a horseshoe set be incorporated into the budget of every such program.

Whether some form of lab manual for the boys would be a good idea, is something each instructor should decide for himself. A notebook into which individual mimeographed sheets of questions could be inserted would provide the boys with a useful record of the main ideas behind their circuits, but on the other hand it would make the whole thing seem more like school work.

The boys should, in any case, be provided with something in the way of literature on elementary electricity. One small paperback book which seems quite appropriate is "Let's Explore with the Electron" by Alfred Bender, available from Stansi for $1.25. A very relevant little pamphlet which should be handed out during the second or third week is "Can I be a Technician", a useful description of various technician careers and the education they require. It is available free from General Motors Corporation, Public Relations Staff, Room 1-101, General Motors Building, Detroit, Michigan 48202.

As every science teacher knows, the best laid plans go oft awry, and even though every effort has been made to design fool-proof projects, some are bound to fail, especially if substitute components have to be used. Anyone taking on a job of this kind must expect to do a great deal of improvising and altering of the devices to fit the needs of the moment, so it is important above all to have available a substantial supply of extra components, scrap metal and wood and other odds and ends to permit spur-of-the moment improvising (and to encourage the boys to do the same). Often electronic factories, TV service shops, university laboratories or national laboratories will have scrap materials or old electronic chassis available free, from which many useful resistors, capacitors, potentiometers, etc. can be scavenged.

Finally, by far the most important single thought to keep in mind in the midst of all these technical details is this: These boys are attempting an ambitious program, which is probably very foreign to them. They will repeatedly get lost and discouraged, and more than anything else will need sympathetic encouragement for their moments of distress, and appreciative praise for their moments of glory. Their exuberant response will more than repay all the effort you can invest in them.

As it now stands, this handbook is only a first attempt. It can be greatly improved if those who make use of it keep track of their specific suggestions for improvement and send them to me at the address below. Any assistance along these lines will be greatly appreciated, and will be acknowledged in the final form of the handbook. Good Luck!

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General Equipment and Supplies

It is essential that each boy have his own tool box, containing tools and small supplies. It is to be given to him at the end of the course, if he lasts that long, but must be left in the workroom of the program until that time. The projects for the first three days have been designed to be built without the tool boxes, and the boxes should only appear as a surprise on the fourth day, when they are needed. This will, hopefully, permit the less serious boys to become bored and drop out before the tool boxes (which may cause quite a flurry of excitement) come into view.

The following box of tools and supplies should be given to each boy.

Quantity	Item	Approximate Price
1	lightweight metal tackle box with divided tray, to be used as tool box (BA #37A231)	3.19
1	30-W soldering gun (Radio Shack #64-2224)	1.95
1	6" screwdriver, regular tip (RS, 64-1831)	.50
1	long-nose pliers, 5" (RS, 64-1825)	1.60
1	wire stripper with adjustable screw stop (BA 37A889)	1.09
1	small hand saw (Discount store?) or coping saw	1.00
10	Alligator clip leads, miniature (Vanco, Chicago, #CL-1, available from Satterfield Electronics, Inc., 1900 South Park Street, Madison, Wis. 53701; price includes tax)	.94
1	roll 60/40 rosin core (not acid core) radio solder	.40
1	tube fast-drying model airplane cement	.15
1	box steel paper clips	.15
1	spool heavy carpet thread	.20
1	12" ruler	.10
1	roll Scotch tape, in dispenser	.25
1	box small box-nails (7/8" x 18 is a useful size)	.15
1	box pan-head sheet metal screws, 8 x 1/2"	.20
2	cardboard fingernail files (like stiff sandpaper sticks)	.10
1	1" x 2" strip of galvanized sheet metal, for scraping insulation from magnet wire	-
1	10-penny (3 1/2") spike, to use as nail set	-
1	pencil	.10
		$13.50

(The solder should be purchased in bulk; see comments below under "4th Day").

Since these inexpensive soldering irons may eventually burn out, 3 or 4 spares should be purchased. Radio Shack has replacement tips (2/59¢) available, and 6 or so on hand for 20 boys would seem wise. Each boy will need two more boxes of solder during the course, as well. The miniature, insulated clip leads listed are excellent but a bit fragile and will need re-soldering as the clips pull off the wires. A larger, sturdier variety (Philmore Test Leads, SA22, $1.35 (10) tax incl.) is also available from Satterfield. At least 2 of these should be included in each tool box, and about 4 more per box will be needed during the course of the program. One #400 Kleen-Tip soldering-iron sponge in a plastic tray should be provided for each 4 to 6 boys (BA #37A3102, $1.13 each). 4 slot-car oilers (OLS, SL-20, 4/$1) or 2 small oil cans will be necessary for electric motors. The total cost of this extra equipment for 20 boys is about $30. If the above suppliers are not used, the best alternative is probably a discount store, which often carries an inexpensive line of tools.

A major irritation which may arise is the possibility of the boys pilfering tools from one another's boxes. At the very least, tools will constantly be mislaid, and it will be impossible to sort them out unless they are permanently marked in some fashion. Rather than using the boys' initials (since one boy may drop out and his tools be passed on to another), labelling all tools in the same box with one number seems the best idea. The ideal tool for this is an "Electric Pencil", a vibrator-engraver (BA 37A9018, $6.95; carbide point 37A9020, $2.49).

Unless shop benches are available for the boys, with electrical outlets, it will be necessary to provide an extension cord leading to each table (preferably hanging from above), into which the soldering irons can be plugged. Most cords have only 3 outlets; if there are more than 3 boys per table, "doublers" will be needed for the ends of the cords. Incidentally, a shoebox, shoebox top, cigar box or similar tray at each boy's place at his work table is a great convenience, for when small components are passed out for a new project, they can be dropped into the tray and so aren't lost in the clutter of tools on the table.

A blackboard in the room is very useful for drawing circuits and writing out words the boys don't know (resistor, capacitor, shunt, etc.)

Additional General Equipment

Quantity	Item	Approximate Price
1	1/4" electric drill, with insulated chuck or 3-wire cord	15.00
1	set high-speed bits for electric drill (RS 64-1836)	2.50
1	5/16" high-speed bit for electric drill	3.00
1	1/2" wood bit for electric drill	1.00
1	small metal-working vise	3.00
2	portable woodworking vises (to clamp on saw horses)	7.00
1	small metal-cutting shears	3.00
4	heavy-duty pliers	6.00
2	large screwdrivers	2.50
1	multi-blade hole saw, for holes from 1" to 2 1/2" diam. (RS 64-1974)	.90
3	metal files, one round, about 1/4" maximum diam.	3.00
1	multimeter (voltmeter, ohmmeter, ammeter) OLS, TE-221)	16.00
		$63.90

In addition, several more tools are essential, but they are rather expensive, and are tools which it might well be possible to borrow from a high school metal-working or woodworking shop, so they are listed separately:

2	hand drills	8.00
4	crosscut hand saws (small size preferable)	20.00
2	large (15") metal-cutting shears	10.00
10	claw hammers, heavy-duty	40.00
2	adjustable wrenches (BA 37A3334)	4.00
1	power saw, small size	25.00
		$97.00

Incidentally, the power drill and saw should be used only by the instructors.

At least two sawhorses (small size to fit the boys) will be needed, to one of which the large spool of 2-conductor speaker cable can conveniently be affixed, on a horizontal piece of 1" dowel.

In addition to the lumber specifically needed for the projects described below, it would be a good idea to have on hand at least the following extra supplies:

	Assortment of model-airplane balsa wood (sticks, sheets)	1.50
10	1/4" dowel rods	1.00
10	3/8" dowel rods	1.50
10	1" dowel rods	2.00
2	2" x 4" x 8' pine or fir	3.00
10	1/4" x 1 1/4" x 6' slats, pine	2.50
2	1" x 4" x 8' pine	2.00
1	16" x 9' x 1" Blue styrofoam FR (flame resistant)	2.15
20 (or more)	extra coat hangers (wire) (used, from dry cleaning shop.	1.50

3	children's scissors	.75	
400	brads 5/8" x 19	2.00	
5	sheets sandpaper	.50	
2	sheets emery paper	.30	
1	box steel wool, medium grade (#2)	.50	
1	spray can of electrical contact cleaner (BA 17A1323)	1.95	
	Elmer's glue; Weldwood contact cement	.50	
	assortment of nails, brads screws, small bolts, washers	4.00	
	assortment of sheet metal scraps: galvanized iron, copper, aluminum, zinc		
	assortment of cardboard and heavy construction paper, spare cardboard boxes and shoe boxes		
	stapler and staples	2.00	
	assortment of colored felt marking pens (at least 10), wide and narrow tips.	2.00	
3	large rolls masking tape, 1/2", 1" and 2"	3.00	
2	rolls friction tape	.80	
3	large rolls paper towling	1.50	
	assortment rubber bands	.50	
1	broom and dustpan (for cleaning up - essential!)	3.00	
	2000' 2-conductor miniature speaker cable, #24 guage, stranded (36F105)	21.80	NEW
	250' 2-conductor phono pickup wire, #32, stranded (36F158E)	5.20	NEW
	assortment of corks	1.00	
50	6 x 1/2" sheet metal screws	.50	
50	8 x 3/4" sheet metal screws	.50	
1	ball string	.25	
25	screw-eyes	.50	
4	circle-compasses	1.00	
15 (at least)	cardboard grocery boxes first-aid kit, including burn ointment, bandaids, eye wash and eye cup.	3.00	
		$67.	

The Blue Styrofoam FR is one of the most versatile materials in the entire stockpile, and should be available in good supply. It is important to obtain the blue FR variety (the color indicates its flame-resistance, an important property, considering the number of hot soldering irons which will be poked into it!) rather than the white, since the blue is finer-grained and more brittle or crunchy, and easier to cut with a saw or knife.

It is available only from Dow; the central plant is Dow Chemical Co., Construction Materials Department, Midland, Michigan 48640. They can supply the names of distributors throughout the country, but the material is widely used as insulation in the construction industry, and is available from many lumber or brick yards. The sheets are 16" x 9', and cost about $2.15 in either the 3/4" or 1" thickness, the 1" being the more useful. It is available as thick as 3". Although some large sheets are useful, it may save time to pre-saw some into 5" x 6" blocks, 2 or 3 for each boy. Although nails, sticks, etc. can be pushed into it, it cannot be glued with airplane cement, which dissolves it.

Another multi-purpose stock item is used band-saw or hack-saw blades, preferably 1/2" wide. A 3" length, for instance, with a hole in one end and a slight bend in the middle, can make an excellent telegraph-type switch if screwed to a board with a sheet-metal screw, with another such screw under the other end for the bottom contact. Any metalworking shop will have plenty of band-saw blades which are normally thrown away. Because they are too hard to drill or to cut with shears, they must be cut into lengths by machine-shop power tools. In addition to those listed for specific projects below, a supply of perhaps one 6" piece and one 3" piece per boy is a good thing to have on hand. All pieces should have a 5/32" diam. hole (to accommodate an 8 x 1/2" pan-head sheet metal screw) machine-punched about 1/2" from one end. The 6" pieces should have two more such holes, about 1/2" and 1 1/2" from the other end, to make them adaptable to all purposes.

The speaker cable and phono pickup wire are included here because they are universally useful. The amounts listed are for 20 boys, and include all the amounts listed specifically in the projects described below, so nothing for this wire need be included in the daily budgets.

Also, lumber will be needed for building the large (perhaps 2' x 2' x 1') storage boxes for the boys. If necessary, they can be built of 1/2" plywood, but this is expensive, probably $5 per box including hardware. The Chippewa group fashioned very useful boxes from two old beer cases nailed together side-by-side, with a large plywood top which made a fine workbench at home. In any case, the box should have a latch and a lock. Padlocks will do, but the keys are easily lost. Dimestores sometimes carry combination locks for under a dollar, which might be better. (Keep a permanent record of all combinations in case the boys forget them.)

Suppliers

The following abbreviations are used for the suppliers from which the various components can be obtained.

AMP - Adams Magnetic Products, 1024 S. California Ave., Chicago, Ill. 60612. Tel. (312) 638-7877. Mr. Weinstein.

BA - Burstein - Applebee, 3199 Mercier St., Kansas City, Mo. 64111. Tel. (816) 931-5863.

CPC - Cadillac Plastic Co., 517 N. Broadway, Milwaukee, Wis. 53202. Te. (414) 276-9700.

ESC - Edmund Scientific Co., 402 Edscorp Bldg., Barrington, N.J. 08007. Tel. (609) 547-3488.

HAM - Hamlin Switches, Inc., Lake Mills, Wis. 53551. Tel. (414) 648-2361. (Magnetic reed switches).
If you wish inexpensive "seconds", contact me directly (K.W. McVoy, Dept. of Physics, U.W., Madison), for Hamlin does not wish to sell them in small quantities.

NEW - Newark Electronics Corp., 500 N. Pulaski Rd., Chicago, Ill. 60624. Tel. (312) 638-4411.

OLS - Olson Electronics, 423 W. Michigan Ave., Milwaukee, Wis. 53203. Tel. (414) 271-9920. Main Store: 260 S. Forge St., Akron, Ohio. 44308. Tel. (216) 762-0301.

RS - Radio Shack, 2615 W. 7th St., Ft. Worth, Texas, Tel. (817) 336-4684. Also, 7340 Lampson, Garden Grove, California.

SAT - Satterfield Electronics, Inc., 1900 S. Park St., Madison, Wis. 53701. Tel. (608) 257-4801.

STAN - Stansi Scientific Co., 1231 N. Honore St., Chicago, Ill. 60622. Tel. (312) 772-3100.

WEL - Welch Scientific Co., 7300 N. Linder Ave., Skokie, Ill. 60076.

All these companies (except Satterfield) have catalogues available on request, which are very useful for tracking down hard-to-find items. BA, OLS and RS specialize in low-cost electronics components. In the supply-lists given below, the numbers in parentheses are the stock numbers from these catalogues.

In addition to these commercial suppliers, it is well to be aware that some state Departments of Public Instruction receive free military surplus electronic components, which they sell to teachers for a nominal charge. They sometimes have excellent bargains, especially in microswitches and potentiometers. An equally remarkable bargain center for military-surplus odds and ends is John Meshna, Jr., P.O. Box 62, E. Lynn, Mass. 01904. Because his stock is continually changing, he has not been listed as one of the standard suppliers, but he carries many items at very low prices and should be checked first. Free catalogue on request.

The Projects Day-by-Day.

(Note: the "Total Cost" listed is for one boy, but includes the full number of items listed on that line. If the price is less than 5¢, it is omitted, as are all prices for lumber.)

First Day - Magnets.

Number	Supplies per Boy	Total Cost	Supplier
2	1/8" x 3/16" x 1 3/4" break-off bar magnets	.40	AMP
1	3/16" diam. x 1" alnico bar magnet	.20	AMP
3	1 1/16" x 3/16" ceramic bar magnet (P-41,107)	.15	ESC
2	1/2" diam. x 3/16" thick disc magnet (P-40,820)	.08	ESC
1	3 1/8" channel magnet (40,847)	2.00	ESC
4"	tempered steel piano wire, #24B.& S.,gauge (5894-05)		WEL
1	styrofoam or paper dish, 1" x 5" x 8" (from butcher shop)	.05	
4	blue styrofoam squares, 1" x 1" x 1/4"		
1	blue styrofoam sheet, 5" x 6" x 1"		
2	tongue depressors (6") (Drugstore)		
1	applicator stick (pharmaceutical, 6") (Drugstore)		
2	balsa sticks, 1/8" x 1/4" x 4 1/2" (Model airplane shop)		
1	drinking straw, paper.		
1	small washer (hole smaller than straw diam.)		
1	1/2" dowel, 8" long		
1	Pine 1" x 4" x 6"		
1	Pine 1 1/4" slat, 4'		
1	1/4" plywood, 4" x 6".		

General supplies: magnetron magnet (borrowed from a high school or university physics lab; #60,461 from ESC for $12.50 will also work); 24 very small compasses for mapping fields (Stansi #3798, $3.00 for 24); assorted pieces of sheet iron, aluminum, copper, plastic, cardboard, etc., to test for magnetic shielding properties; box of steel and brass common pins, mixed. (Steel pins are not at all easy to find, since they seem to have largely been replaced by jacketed brass ones which look exactly the same. Use a magnet to distinguish them.) The piano wire, about the thickness of a pin, may be obtainable from a local music store. That from Welch is 55¢ for an 8 ft. spool, which is more than adequate. After using them whole, the break-off magnets can be broken in half to make 7/8" long magnets, to demonstrate that, new poles appear at the break.

The first day is devoted to "fooling around" with magnets, to let the boys feel magnetic forces for themselves (caution them about the powerful magnetron magnet, whose keeper can be very dangerous, and which will also magnetize watches) and see that magnets have two kinds of poles. Magnets make a more reliable beginning than electrostatics (which can be difficult in humid summer weather). Both are fairly "dull" compared to circuitry, but for this very reason are useful in filtering out those boys who have no real interest in science, and merely show up the first day or two out of curiosity.

1. N & S poles. Fill low (non-magnetic) dish with water and float small bar magnets (alnico, with poles on ends, and ceramic, with poles on sides)

on bits of styrofoam or wood chips to make compasses. Identify N poles and mark with scratch or masking tape. "Tow" them with another magnet from above or below the table. Let boys discover how to distinguish steel from brass pins (identical in appearance) with magnet. Magnetize pins or needles and float on water (carefully!) as compasses; note how their ends attract or repel each other. Test materials for magnetic properties; find magnetic minerals in sand.

Ten-cent stores often have a "magnetic game" consisting of some type of iron filings or iron oxide in a powder or tiny-crystal form, packaged loosely in a flat plastic box attached to a piece of cardboard. It is excellent for demonstrating magnetic field lines (no mess because it is sealed), and a few should be left lying about for the boys to play with. One manufacturer is Smethport Specialty Co., Smethport, Pa.; theirs is called "Woolie Willie" and costs about 20¢.

2. Further explore interactions of magnets by suspending one on a thread (fasten with scotch tape) hung from a bent coat hanger and attract or repel it with a second magnet . Try to separate two channel magnets stuck together. Snap off a 1/2" piece of tempered piano wire, magnetize it, and explore the field of a channel (or magnetron) magnet with it, by "hanging" it magnetically from another such piece of wire. (The wire can be tempered, to harden it and make it brittle, by heating it to a glowing red and immediately dunking it in a pan of water. The heating can be done with a Bunson burner or butane torch (only 2" or 3" at a time), or by sending a current through it (carefully!) with a Variac. If piano wire is not readily available, thin steel sewing needles can be used if tempered snap off the points to avoid

punctured fingers.) Explore field of magnetron magnet with brad magnetized to paper clip. Stick brads on magnet like porcupine quills.

3. Channel Magnet Stand. Build the wooden support shown, with channel magnet mounted in a hole in base, and dowel - spool at top for thread to suspend ceramic magnet; when swung, it will "dance" about the channel magnet. Change height while dancing. Upside down, the bar magnet will hang "up", held up by the channel magnet. In this position, use it to test sheets of various materials for magnetic shielding by sliding them between the two magnets to see if lower one will fall.

4. Coupled magnetic pendulums. In knife-slits in 5" x 6" styrofoam base, insert tongue depressors vertically. Scotch-tape 2 break-off magnets (7/8" long) to ends of 4 1/2" balsa strips, tape other ends of strips, T-wise, to 2" lengths of drinking straws. Insert applicator stick through straws, with washer separating them, and insert stick through small holes at tops of tongue depressors. The pendulums are nicely coupled magnetically, so that if one is started swinging, it eventually transfers its energy to the other, then back to first, etc. If boys are interested, try making longer supports, with 3 or more pendulums.

A much higher-frequency version can be constructed on a channel magnet, by opening a paper clip into a U - shape in such a way that one leg (left double) will stand flat on the magnet. From the end of the opposite leg a 1" brad can be suspended magnetically, which makes a high-frequency pendulum when twanged. Several in a row on the channel magnet will couple so as to send a wave down the line when the end one is twanged.

General Remark: Since many of the boys may be quite unfamiliar with the proper use of hand tools, especially saws, it is a good idea to offer them careful individual assistance when ever they encounter a new tool for the first time.

2nd Day. More Magnetism.

Number	Supplies per boy	Total Cost	Supplier
	1. Shoe Box Magnetic Spinner		
1	Shoe box		
1	1" dowel, 7" long		
1	Sewing elastic 6" long, to use as belt drive		
1	Tongue depressor		
1	Sewing spool		
1	1/4" dowel, 4" long		
1	Fir 2" x 4", about 5" long, to fit crosswise in box		
3	1/2" diam. x 3/16" thick disc magnets (P-40,820)	.12	ESC
	2. Magnetic Diviner		
1	1/4" plywood, 8" x 8"		
3	1/4" dowel, 11" long		
1	1/4" dowel, 9" long (approx.; cut to fit)		
10	1/2" disc magnets, as above	.40	ESC
2	Very small screw eyes.		

General Supplies: Miscellaneous lumber, including 1/2" dowel, to make crank handle for shoe box project; 1" circle saw to cut holes in shoebox to fit 1" dowel snugly; tube of white graphite; magnetron magnet, slab of aluminum approximately 1/4" x 4" x 20".

1. Shoebox magnetic spinner.

This was originally a model of a chemist's magnetic stirrer, but since it was unfamiliar and failed to elicit much enthusiasm, we turned it into a game. The 1" dowel is mounted transversely near one end of the shoebox as a crank. Near the other end a piece of 2" x 4" is fitted transversely and tacked in place, with a piece of 1/4" dowel mounted vertically in it, projecting to within about 3/8" of the top of the box. The spool rides on this dowel and is driven from the 1" dowel crank by a loop of sewing elastic with a half-twist in it. A tongue depressor (cut off to fit crosswise in the box without touching the sides) is mounted (e.g., with masking tape) across the top of the spool, with button-magnets mounted on top of it, at either end, so that they revolve in a circle when the crank is turned. Finally the top of the box is replaced, and another button-magnet laid on it, which will follow one of the internal magnets in amusing fashion when the crank is turned. Two magnets on top would be even better, but this seems to produce too much friction, and the armature generally refuses to turn. Incidentally, this friction can be reduced by a metal nut or a chip of wood, etc., taped above the spool, which is thick enough to prevent the spool from riding up its dowel, so the inside magnets do not rub the box top. A bit of graphite (preferably the white variety) on the boxtop under the magnet also helps.

The boys will inevitably think up competitive games with the gadget. E.g., who can rotate the magnet fastest without throwing it off? or who can throw it farthest when it does come off? etc. To prevent the magnets

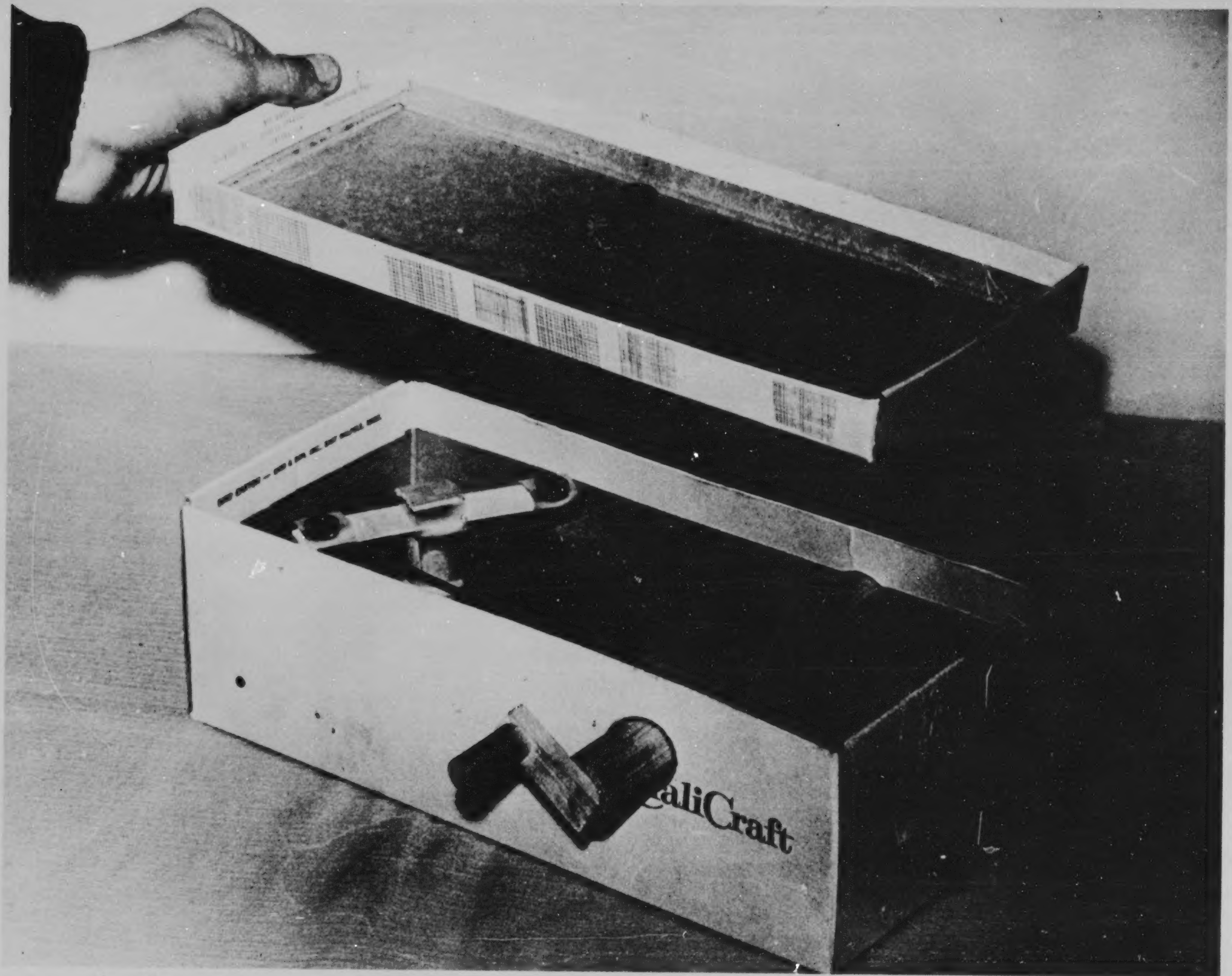


Fig. 2 Shoebox Magnetic Spinner

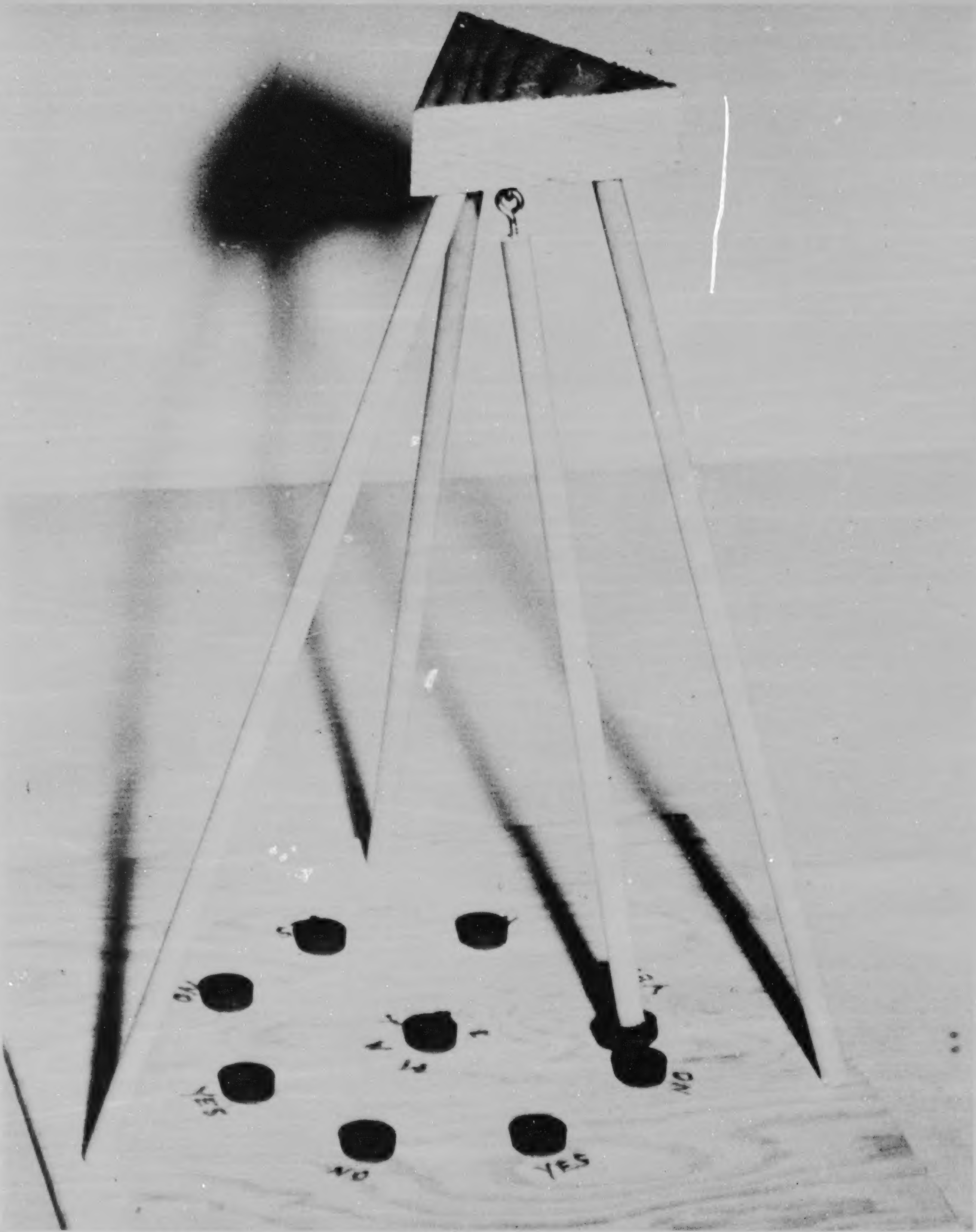

NO
YES
NO
YES
NO

Fig. 3 Magnetic Diviner

from flying around the room, the top can be inverted, and held in place with tape.

2. Magnetic "Diviner".

This is a copy of a commercially - available ($10!) game. Construct a tripod by inserting the three 11" dowels into angled 1/4" holes drilled into a small block of 1" pine. Open a small screw - eye slightly and screw it into the under side of the block. Glue a button magnet to the end of the 9" dowel (the end must be sawed square) and cut the dowel to such a length that, when the other screw-eye is screwed into a small hole drilled in its opposite end, it will miss the baseboard by about 1/4" when hanging vertically from the tripod; fine adjustment can be made with the screw-eyes. Carefully drill a 1/2" hole in the center of the plywood base, just deep enough that a button magnet glued into it will be about flush with the top of the board (not shown correctly in the photo), and glue the rest of the button magnets accurately in a 3 - 3/4" diam. circle around it (without drilling). These magnets must all be oriented to attract the one on the stick. With the tripod positioned over the circle, the central dowel is swung like a pendulum, whereupon it "wanders" in intriguing and erratic fashion from one magnet to another, losing its energy very gradually. Eventually it will settle on one of the magnets. (It is essential that the tripod be centered accurately over the circle.) It is particularly amusing if the lower magnets are covered by a sheet of paper or cardboard. Alternatively, it makes a fine "diviner" by marking the circle magnets alternately "yes" and "no", and the center one "maybe"; ask it a question and see where it stops.

3. Demonstration of magnetic damping. Although only ferromagnets like iron are affected by magnetic fields when at rest, any conductor is affected if it moves relative to the magnet. This is very nicely shown by a magnetron or other powerful magnet and a thick sheet of aluminum (or copper), about 1/4" x 4" x 20". At rest, the aluminum is not attracted by the magnet, but if you try to slide the aluminum sideways between the poles of the magnet, the motion is strongly resisted. Let the boys feel it for themselves. Also, it is impressive to hang the aluminum sheet from the ceiling by two strings, so it can be set swinging (along its own length) toward the magnet gap, but will be stopped abruptly when it enters the gap. This is the principle of magnetic damping used in chemical balances, electrical meters, etc.

3rd Day. Electrostatics

Number	Supplies per boy	Total Cost	Supplier
	Lucite Rod Game.		
2	Extruded acrylic rod ("lucite"), 1/2" diam. x 1' long	.54	CPC
1	Coat hanger (as support for lucite rod)		
1	4" square of wool blanket material		
1	Polyethylene coffee can cover		
	Capacitors & Neon Lamp Flasher		
1	200 V - 0.1 mfd mylar capacitor, Mallory PVC-201 (13F797)	.22	NEW
1	200 V - 0.5 mfd mylar capacitor, Mallory PVC205 (60F2250)	.38	NEW
1	200 V - 1.0 mfd mylar capacitor, Mallory PVC21 (60F2251)	.66	NEW
4	470 K resistors, 1/2 watt, 10% tolerance (13F050)	.40	NEW
2	45 - V batteries		
1	Neon glow-lamp, wire terminals, NE2A (12A4129)	.08	BA
2	Clip leads, Vanco miniature	.20	SAT

Comments: The neon glow lamps from BA are 10 for 79¢ or $3.59 for 50. At least one more per boy is necessary on the 14th day. The capacitors are non-polar, so the boys can connect them either way, and they have a sufficiently large voltage rating that there is no danger of their breaking down. If 67.5 - V lantern batteries are more readily available than the 45 - V ones, so much the better (2 in series will still be necessary), but in this case, 2M or 3M resistors will be more suitable than the .47 M ones. The 45 - V batteries are often available in school - supply military - surplus stores for 25¢ or so; they are often old, with too high an internal resistance to be of use for much else, but will serve fine for this purpose. If they must be purchased new, the best buy is a single 90 V one ("B" battery, Newark number 49F355, Eveready number 479), available for about $3.00. The point of the high voltage is that the neon lamps will not fire at much less than 90 V.

1. In a dry climate, many amusing electrostatics experiments can be done, such as charging balloons by rubbing with wool and hanging them from threads to observe their repulsion, or making 1/2" hollow balls from aluminum kitchen foil, which can be suspended from threads and charged (both by induction and by direct contact) with hard-rubber combs, the lucite rods, or the polyethylene coffee can covers which have been rubbed with wool. A quite serviceable electroscope can even be made from a 15" length of very fine (say, #36) and flexible wire, with an aluminum-foil ball at each end, bent double and hung over an insulating support. When charged, the

balls will repel each other; they can be completely discharged by touching with a finger, or discharged in small steps by touching with a piece of metal of very small capacitance, such as the metal band around the eraser of a lead pencil, or a nail or paper clip stuck into the eraser for insulation.

2. In many locations, however, summertime weather is too humid for these devices; surface moisture, even on most good insulators, provides a conducting path through which charge leaks away. Lucite and styrofoam seem to make the best non-leaking conductors.

Styrofoam can be used as a quite spectacular "condenser" for storing charge. Wiping a piece of wool blanket across a large sheet of it will fix a substantial charge on it, at a high enough voltage that, if a neon lamp is held by one terminal and moved so that the other terminal is wiped across the charged stripe (or even waved past, within 1/4" of the styrofoam), a (harmless) discharge will occur through the lamp and into your hand. It will fire the bulb, but only rather weakly, so that it can only be seen in a darkened room or closet. If two or three stripes of charge are "painted" onto the styrofoam, and the lamp waved transversely across them, it provides excellent evidence that the electrons have really been "stuck on" where the cloth wiped them on.

3. Lucite Rod Game. Good strong electrostatic forces can be seen by suspending one of the lucite rods on a thread at its center, and rubbing one of its ends, as well as one end of the other rod, with the wool blanket. These charged ends will repel, and the repulsion can be used to cause the

suspended rod to rotate. This could make a fine competitive game (who can rotate his rod fastest?), except that it is too easy to cheat by tapping the two rods together. Fortunately the wool will give a polyethylane coffee can cover an opposite charge, so the game can be played by pulling the rod around with the cover. A channel magnet makes a good prize for the winner.

4. Capacitors as Storage-Chambers for Electrons.

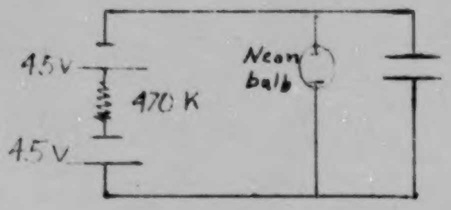
First, since the two 45 - V batteries are needed in series to fire the neon bulbs, it is a good idea to use a 470 K resistor to connect them, so the bulb and battery are permanently protected from being shorted; taping the batteries together with masking tape will save the connecting resistor from punishment.

The most basic idea is simply to charge up the 0.1 mfd capacitor (the larger ones are a bit hard on the bulb) from the batteries and discharge it directly through the neon lamp, thus demonstrating that it does indeed "hold electrons". The connections are facilitated by clip leads, which also demonstrate that wires act as "pipes" for electrons. It is also impressive to discharge a condenser (especially the larger ones) by simply shorting a clip lead or screwdriver across it, to see it spark.

The next step is to show that the "burn time" of the lamp can be lengthened by putting a resistor in series with it. The hand-to-hand resistance of a person is generally several hundred K, which is enough to lengthen the burning time to a second or so, using the 0.1 mfd condensor. One or two 470 K resistors in series provide a more reproducible burning time, and it is then easy to show that the 0.5 and 1.0 mfd capacitors do, indeed, have a greater "electron-capacity", for they provide correspondingly longer (and equally bright) burns than the 0.1 mfd capacitor.

Another nice (though perhaps less obvious) demonstration of larger and smaller capacitances can bo obtained by charging up the 1.0 mfd capacitor, and discharging it into the 0.5 mfd through the lamp (with or without a series resistor, whichever is preferable). Only a quarter or so of the charge will be transferred to the smaller capacitor, which can be discharged by "shorting" it with two fingers, whereupon it can be used to draw off more charge. 3 or 4 repetitions are necessary to discharge the larger capacitor to the point where it will no longer fire the lamp. If the 0.1 mfd is used in place of the 0.5 mfd, 15 or so repetitions are needed.

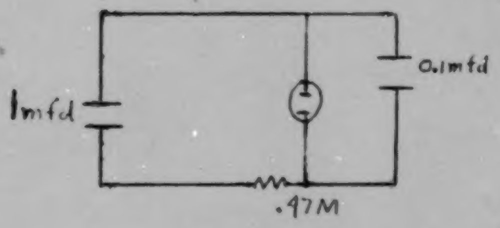
5. RC Neon Lamp Flasher.



This makes a fine take-home project, but since it needs to be soldered together for durability, and it is probably advisable not to hand out the individual tool kits until the 4th day, they can simply be put together with 2 clip leads for today (one clip-end of each lead can hold both a lamp and capacitor terminal), and soldered up permanently tomorrow.

It is most convenient to use the 470 K resistor between the batteries as the resistance; any one of the capacitors (or combinations) can be used, to give a convenient range of frequencies, the larger capacitor, the lower the frequency of oscillation. (The period is roughly RC, or about 1/2 sec. for .47 M and 1 mfd.). The circuit depends for its operation on the fact that the neon lamp will not fire until the voltage across it (i.e., across the capacitor) reaches about 75 V. When first connected, with the lamp off, one has a standard RC oscillator, with most of the voltage drop initially across the resistance. As the capacitor charges up, the voltage across it increases until it reaches the firing - voltage for the lamp, whereupon it discharges through the lamp, carrying its voltage down below the firing - voltage, and the charging cycle starts over again. Incidentally, when soldered together, there is no way to turn off the circuit (it uses so little current it will last for years). To prevent it keeping people awake at night, have the boys make black-paper caps for the lamps.

6. Finally, as a finesse if any of the boys feel ambitious, the same RC oscillator can be built with R=o.47M, C=0.1 mfd, and a charged-up 1 mfd condensor as the current-source, in place of the battery. Since the two condensors are in series, it is mainly the smaller one which fixes the oscillation frequency, at about 20 cycles per second, and the whole thing "runs down" in about a second, as the charge from the larger condensor is exhausted.



7. If there is any time left, and a van de Graaf or other electrostatic generator is available from the local high school physics lab, this is the appropriate time to set it up and let the boys draw sparks from it, fire neon lamps by holding one wire and pointing the other at the generator terminal, charge up capacitors and use them to fire neon lamps as above, etc. It is always impressive to have two boys each hold a terminal of a neon lamp, and then have one of them draw a spark from the generator, which will fire the lamp as part of the charge travels to the other boy. Firing several lamps in series (with a boy between each pair if desired) is also good fun.

4th Day. Series and Parallel Circuits

This is the day to pass out the individual tool boxes, since the soldering irons will be needed from now on. Also, a liberal supply of insulated hookup wire (preferably #20 or 22 stranded copper, which is more flexible than solid wire) should henceforth be available every day. Since it is necessary for all further projects, it will not be listed explicitly among the supplies. Although not a very expensive item, it is one which can very likely be scrounged (in the form of scraps preferably a foot or more in length) from any friendly nearby electronics company. For a group of boys who all need a piece at once, it is actually more convenient in this form than on a spool.

Number	Supplies per boy	Total Cost	Supplier
2	GE #14 flashlight bulb for 2 D cells (2.5V,0.3A)	.23*	NEW
3	D-cell flashlight batteries (1.5V) (BA-53)	.24	OLS
3	Flashlight bulb sockets, screw base, soldering terminals, no mounting bracket (25F451)	.69*	NEW
1	GE 113 flashlight bulb, for one AA cell (1.3V, 0.22A) (25F140)	.13*	NEW

General supplies: 1 pad medium grade (#2) steel wool for entire class. Alternatively, 10' fuse wire, 1/2 Amp. (5891-06, WEL), 10¢.

* The prices quoted for bulbs and sockets (as well, of course, as for batteries) are quantity prices, the bulbs for lots of 10-99 and the sockets for lots of 25-99. The unit socket price drops to less than half this for lots of 250-499.

Remarks on Solder: It is far cheaper to buy the solder in bulk rather than in the small quantities hardware stores have available. Kester 40/60 rosin-core solder, 1/16" diam., is standard, available from BA (17A7047) for $1.73 per 1-lb. spool. Three such spools should be purchased for 20 boys, and in addition one 1-lb. spool of Ersin 5-core solder (BA, 17A7029), for $3.40; this has a lower melting point and should be saved for soldering wires to batteries and power transistors.

Solder rapidly becomes an item of considerable value in a class of this sort, and may tend to vanish from tool boxes if not watched. The temptation can be minimized by only handing out 1-foot lengths.

1. Since this will be their first introduction to soldering, the boys will need instruction on tinning their new irons (clean them with steel wool, plug them in, and melt solder over the tips as soon as they get hot the first time, to cover the copper and prevent it from oxidizing), on the use of the moist wiping sponges (keep eyes away from small drops of molten solder which may be snapped off an iron by the sponge), and on stripping and soldering wires together (twist the strands tight after stripping, tin each wire, twist them together, and heat the wire joint (not the holder) while feeding solder into it). A demonstration is a good idea. One way of giving them practice in soldering several joints is to have them solder 4" lengths of wire into closed loops, interlocked to make a "daisy chain" several loops long. Incidentally, each boy should make a stand to rest his hot soldering iron on from a 10" length of coat-hanger wire.

2. Next it might be wise to solder yesterdays neon lamp flashers together to make durable ones they can take home. A convenient configuration is obtained by hanging the capacitor by its leads at the side of the battery pack, with the neon lamp, upright, supported by its leads soldered onto the same capacitor terminals. The resistor is between the two batteries. Have each boy draw the circuit on a large piece of masking tape and stick in on the side of the battery for future reference.

3. Series and Parallel Circuits. Although there is something to be said for laying out circuits neatly on a board, it seems preferable to merely clip these simple ones together as described below. This makes them temporary and "experimental", and makes it easy for a wandering instructor to ask a boy to construct a particular combination, or to repeat it for emphasis the following day. Each circuit, however, should carefully be drawn on a piece of paper, with its descriptive name ("one lamp in series with two batteries", etc.), and perhaps taped to the inside of the storage box.

The clipping is greatly facilitated by constructing two "test lamps", which are useful additions to the tool box (don't send them home) in any case. Each is made by simply cutting one of the smaller-sized clip leads in half (in the middle of the wire), stripping the cut ends, and soldering them to one of the bulb sockets (one without a mounting bracket). Use a GE #14 bulb in it, which gives a perfectly visible light on one D-cell (fine battery tester later on, when dead batteries begin to accumulate), and is not burned out by two.

By far the simplest way to use D-cells without expensive battery holders is simply to solder leads on each end. Because the bottom end especially is a good heat sink, this can be tricky at first, especially if the iron tips are small, and the boys should have had a fair bit of soldering practice before trying it. The trick is to let the tip get as hot as possible, lean the battery upside down against something so it can't move and apply a flat face of the tip to its bottom, at the same time working solder under it. It may be necessary to let the iron re-heat before attempting to fasten the (tinned) wire to this blob of solder.

The 8¢ Olson D-cells, however, which are the most economical, have an aluminum case, which doesn't accept solder. They do have a cardboard jacket, however (unlike Ray-O-Vac), and it can be used by soldering a wire just under the head of a very thin box nail (5/8" x 19 works well), and carefully inserting the nail between the aluminum case and cardboard jacket, with needle-nosed pliers. The center terminal, though a bit difficult, can be soldered.

The internal resistance of a new D-cell is so small compared to that of a #14 bulb (8Ω) that the bulb burns almost equally brightly whether it is being driven by one battery or by two in parallel. Consequently there is no use for two batteries in parallel (in this application), so the boys may as well solder two of their batteries in series right off. That end of the connecting wire which is soldered to the center post of one battery should be soldered on leaving about 1/4" of bare wire free, to enable the use of one battery at a time if desired. (Have the boys check that either battery can be used from this terminal!)

To begin with, clip one of the "test lamps" across one battery, and then short it out (briefly!) with a screwdriver, etc., across the socket terminals. It's their first acquaintance with a parallel circuit; have them draw it as such and explain why the light goes out (current takes the path of least resistance through the shunt).

To show that there is current being drawn from the battery (much more than when the lamp was on!), a very simple but effective fuse can be constructed and put in series with the bulb, which will blow when the bulb is shunted. It is simply a short piece of fine iron wire, but it will burn through only if it is very short, so that enough current will flow to heat it. Drive two small box nails the same depth into any piece of wood, one beside the other so that the gap between their heads is not more than 1/16". A single iron strand from a pad of medium grade (#2) steel wool is stuck onto a piece of scotch tape, which is then stuck, wire down, onto the nail heads. The nails are the terminals of the fuse to which the clip leads are easily fastened. The 1/16" of iron wire in the circuit is readily burned by a single D-cell, and the flash can be seen through the tape. It will not burn when the bulb is in the circuit.

As the next step, move the clip lead of the test lamp so that both batteries are in the circuit, to see that the bulb gets brighter.

Third, compare series and parallel connections of the two bulbs, first using both batteries in series. Connect the two bulbs in series and observe that unscrewing one from its socket will turn both out, and that shorting one across its socket terminals makes the other burn more brightly. This type of thing is interesting and fun only if the kids are thinking about what they are doing. Having each draw the circuit before hooking it up will help, but it is also a good idea to ask them to guess in advance what will happen. Since very little equipment is necessary for these experiments, it might be a good idea to make it a group effort by having them (after the soldering is completed) use the lids of their storage boxes as workbenches, with the boxes arranged in a large circle on the floor. This makes it easy to keep everyone together, and to encourage everyone to guess what will happen when a certain bulb is unscrewed, etc.

Finally, put the two bulbs across the 3 V in parallel, and see that again either unscrewing or shorting one of the bulbs will turn that bulb off, but this time , amusingly, the other bulb goes off when the first one is shorted (since the same shunt shorts them both; this may be mysterious at first, since the shorting is done at the terminals of one socket; have the boys check that the shorting can equally well be done - perhaps with a clip lead - across the battery terminals, where it is symmetric to both bulbs), and the second bulb is nearly unaffected when the first is unscrewed (like a parallel string of Christmas tree lights).

4. D-cell flashlight. To put all this theory to some practical use, let each boy build a simple "flashlight" by first soldering one of the lugs of a bulb socket to the center front of a D-cell. This is again fairly tricky with small irons, but with care can be done if the solder is applied, alone, to the center part first. A single wire from the other

socket lug leads down the side of the battery, with a right-angle bend when it reaches the bottom. Its last half inch or so is stripped of insulation so it can make contact with the bottom of the battery to serve as a switch. If the wire is taped to the side of the battery, near the bottom, its own stiffness will hold the switch in the normally open position, and it can be conveniently closed by pressing with the thumb. A GE 113 penlight bulb (with a built-in prefocussed lens), though slightly overdriven by a D-cell, will probably last as long as the battery and turns the construction into a handy (if somewhat fragile) little flashlight the boys can show off to their friends. Incidentally, the boys should be warned that two D-cells in series will burn out the penlight bulb.

5th Day. Switches and Applied Circuitry.

This is primarily a "fun day", designed to give the boys a chance to put their soldering to practical use.

Number	Supplies per boy	Total Cost	Supplier
	1. Light - Signalling Device		
2	GE #123 flashlight bulb, for 1 D-cell (1.5 V)	.20	
2	Flashlight bulb socket, screw base, soldering terminals, right-angle mounting bracket (25F1318)	.23	NEW
2	8' length of 2-conductor miniature speaker cable (#24, stranded) (36F105)		NEW
2	1/4" #8 round-head iron bolt, and nut	.05	
2	3" lengths of solid copper wire, about #22		
2	Empty, clean tin can.		

2. SPDT Switch

2	GE #14 bulbs (2.5 V, 0.3 A)	.21	NEW
2	Flashlight bulb socket, screw base, soldering terminals, no mounting bracket (25F451)	.23	NEW
2	D-cells	.16	OLS
1	SPDT spring-loaded micro-switch (18C193)	.33	BA
1	Pine or fir 2" x 4" x 6"		
1	Miniature alligator clip (28F528)	.05	NEW
1	Fahnestock clip (30F362)	.02	NEW

3. Variable Resistance

1'	#32 chromel resistance wire, 10.55Ω/ft. (5885-30)		WEL
1	5Ω potentiometer (knurled shaft, wire wound), SW. (14A1099)	1.19	BA

General Equipment:

4	6" x 6" sheets of copper		WEL
4	6" x 6" sheets of zinc (or galvanized sheet iron)		
1	Low-current bulb, GE#48 (2V, 0.06A) (27F122)	.22	NEW
10	Tongue depressors, wooden		
1	Non conducting basin (e.g. plastic) for metal sheets		
	Salt		
1	DC Milliameter, about 10 mA full scale (35A6004)	4.50	BA
1	DC Microammeter, 100 μA full scale (35A6170)	4.95	BA

(Note: if this 100 μA meter is not in stock, #35A6000, a 500 μA meter, at $3.20, will do. On the other hand if the Olson multimeter (TE-221) has been purchased, it has a 0-50 μA scale, which can be used just as well.)

At least half-a-dozen push-button SPST or SPDT switches will be needed per boy for various projects built throughout the course. The clearest and cheapest SPST is a home-made one built of a 3" piece of band-saw blade or sheet metal (punched with a hole near one end) and 2 sheet-metal screws, all mounted on a board. Probably the nicest commercial switch is a SPDP micro-switch (without leaf or other special action), which usually has mounting holes through which nails can be driven (carefully), preferably into an end-grain of a wooden base.

The cheapest commercially-available one is (18C256) from BA, 49¢ each in lots of 10. By far the more attractive bargain, though, is available at many school-supply electronic military surplus outlets, where these little switches sell for a nickle apiece.

Another alternative is the larger BA version, the SPST one (18B770) selling for 5/99¢ .

The smallest amount of #32 chromel wire commercially available is a 1660 - ft. spool from Welch (5885-30) for $5.95.

Unfortunately the electronics supply houses don't carry 1.5 V bulbs like the GE 123, but most hardware or drug stores have them.

1. Light-signalling Device.

Mount the flashlight bulb socket with mounting bracket inside the bottom of a tin can (a soup or coffee can is good) with the 1/4" bolt and nut, after soldering a 5' length of speaker cable onto the lugs. A knot (for strain relief) should be tied in the cable inside the can, before it is threaded out through a separate hole in the bottom of the can. At the other end of the cable, solder one lead to the center post of a D-cell and the other preferably to a 3" length of bare , solid copper wire (about #22). This is bent into hairpin shape, with the two ends soldered together and to the speaker cable lead. Its purpose is simply to provide a thumb-switch like that used on the flashlight above (the speaker cable has very little "spring"), which it does by being taped to the side of the battery, with the "top" end of the hairpin bent over the bottom of the battery to make contact. It makes a perfectly passable telegraph key, but if a fancier one is desired it can easily be made from 4" of hack-saw blade (with a pre-punched hole) fastened to a board with a 1/2", #8 pan-head sheet metal screw, with another such screw for the lower contact. Use a GE 123 or other 1.5V bulb.

The gadget works fine for signalling between two houses at night, and cannot be seen from the side. Since the switch is separate, the light can be mounted outside a window, in a tree, etc., if desired. Have each boy

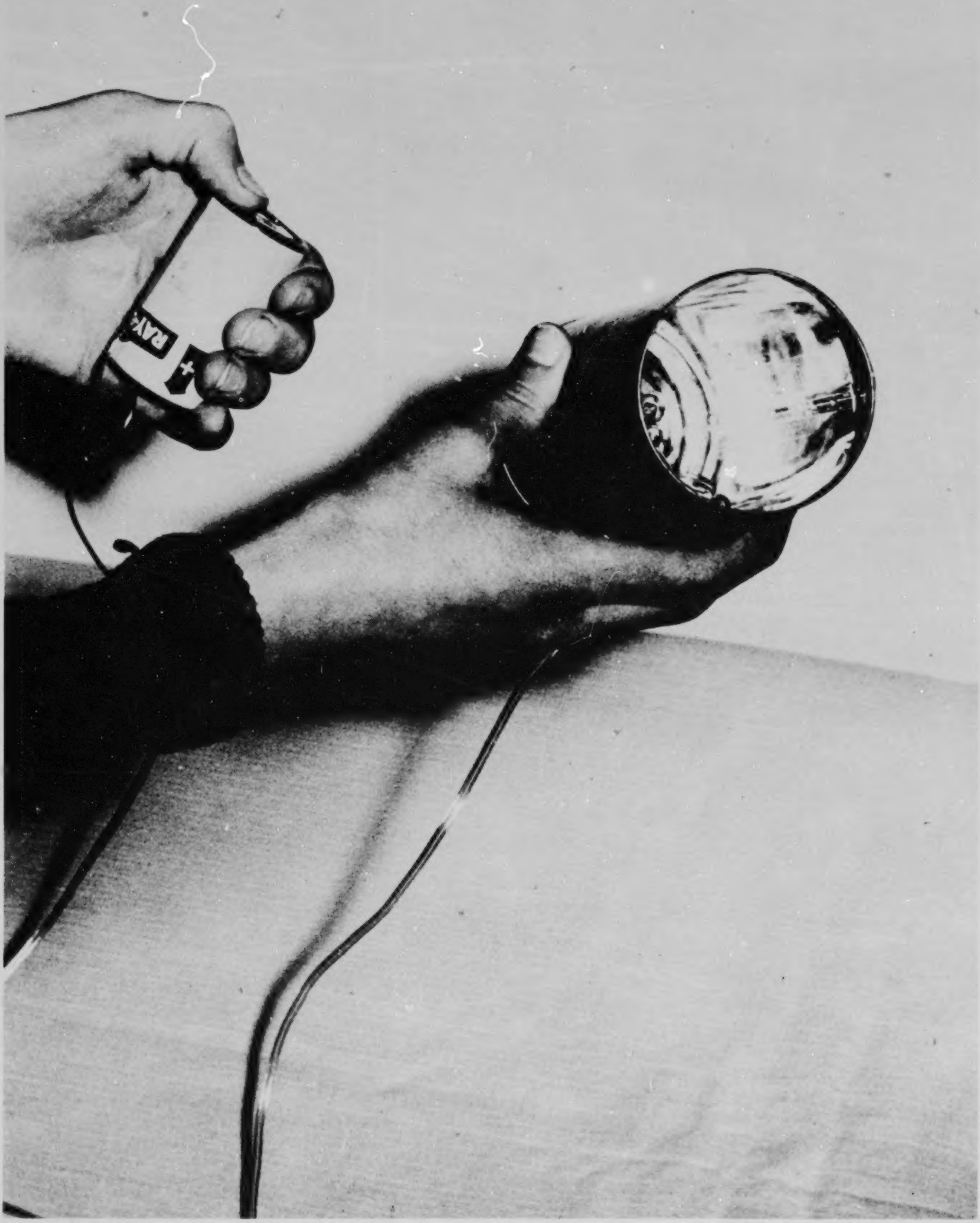


Fig. 4 Light-Signalling Device

make a copy of the international Morse code and tape it to his tin can.

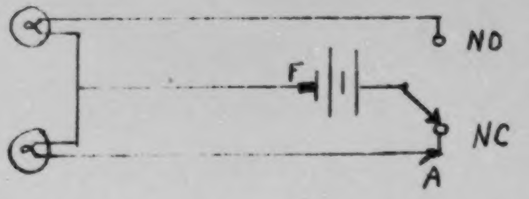
Although it may seem tedious, it is a good idea to have each boy sit right down and build a second one. There may very well be no one else in the course living within sighting - distance of his house, and he can give his second signaller to a friend who does.

If the boys are particularly interested in decorating some of their projects, this is one which lends itself naturally to decorating. Lacquer or water - colors might be used, or perhaps the boys will have other materials to suggest. If plenty of insulated, solid - copper wire is available, a nice effect can be achieved by carefully winding a single layer on the can, anchoring the ends in small holes punched through the side. The hookup wire used by the telephone company is ideal, for its insulation is a solid color with a spiral stripe superimposed, which produces an interesting effect something like porcupine quills when wound on a can. Alternating bands of different - colored wire make an attractive effect.

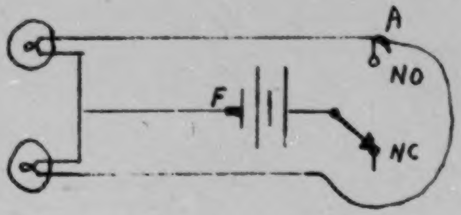
2. SPDT Switch.

An amusing effect can be obtained by cutting out animal or human figures from cardboard (a piece of a box will do) and using GE #14 bulbs for the eyes, screwed through the cardboard into sockets at the back. The SPDT microswitch can be mounted at one end of a length of 2 x 4 and the figure at the other, and so arranged that operating the switch either makes the light jump from one eye to the other or makes both blink on and off together. The batteries can be taped down to the board, or held in place on it between spikes.

Since the shift from alternate to parallel operation of the bulbs can be effected by changing a single wire, this wire is provided with a miniature alligator clip (A), which also serves as an overall on-off switch. To facilitate a modification explained below, the two bulb terminals which are connected together should be connected to the battery with a Fahnestock clip (F).



Alternate



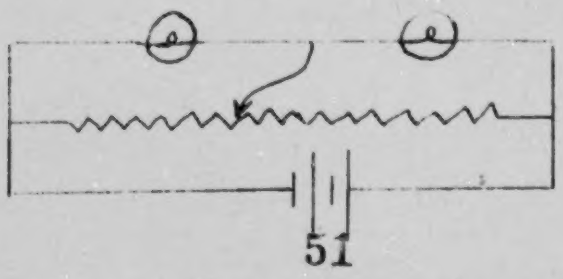
Simultaneous

(The "permanent" side of the clip is screwed to the battery lead.) One lug of one socket is permanently connected to the "normally-open" contact of the switch, and one battery terminal to the "common contact". The other lug of the other socket is clipped to the "normally closed" contact for alternate operation (there is no "off" position in this case), and to the "normally open" contact for parallel operation. Be sure that the boys recognize this as a parallel connection, and have them draw both wiring diagrams in a configuration that makes this obvious.

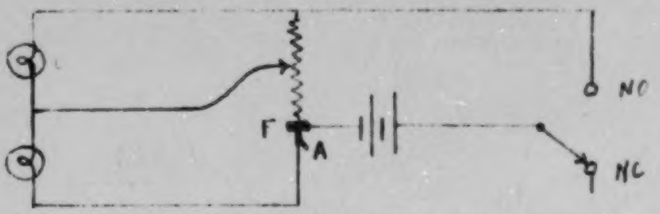
3. Variable Resistance.

The clearest introduction is with a piece of chromel (high resistance) wire. With flashlight bulbs, only a few ohms are necessary; a foot of wire with a resistance of about 10Ω/ft. is ideal. Since it is impossible to solder, it can either be stretched between two nails on a board, with its ends wrapped around the nails, or simply used with clip leads.

First just put a variable length of it in series with two D-cells and a GE 14 bulb - one of the test lamps is convenient, sliding one clip lead along the wire to vary the resistance in series with the bulb. It is also a good idea to put the resistance alone in series with the batteries (this will draw 300 μA, so it can be left on for a few minutes, but preferably not longer) and use the clip leads of the lamp to "tap off" a variable voltage by putting the lamp in parallel with a variable length of the wire. (Since voltage will still be a complete mystery, explain the operation in terms of the "rest" of the resistance wire, the part which is in series with the lamp.) More fun can be had by using the resistance as a true voltage divider, with complimentary parts of its voltage drop going to two



lamps, so that as the center contact is moved, one lamp gets brighter and the other one dimmer. This can be done with the two eyes of the above figure conveniently by disconnecting the common bulb lead from the Fahnestock clip at one end of the battery, and fastening the alligator clip on one of the other bulb leads to the Fahnestock clip in its place. If the chromel wire is put in from the Fahnestock clip to the (NO) terminal of the switch, the circuit will normally be open. It is closed through the chromel wire by depressing the switch, and the common bulb lead can be moved along the chromel wire as a sliding contact to vary the relative brightness of the two bulbs.



If low-resistance potentiometers (about 5 ohms) can be afforded (they are normally wire-wound and cost around $1.25 but are often available as military surplus for 25¢; they should have a voltage rating of at least 5 watts), they will be found very useful for regulating the speed of slot-car motors, etc., and this is a very appropriate time to hand them out. It is very convenient again to snip a clip lead in half and solder the snipped ends to the center and one end-terminal of the pot. The pot can then (with the help of one more clip lead) be substituted for the above chromel wire (but draws 600µA from the batteries). It should not, however, be sent home at this time, but be kept in the tool box for later use; the chromel wire can go home now.

4. Copper - Zinc Battery

For a change of pace, it is interesting to construct a simple battery. One made of a single sheet of copper and a single sheet of zinc, both dipped far enough into a (non-conducting) basin of water to wet a few square inches of each, will generate a current between them of a few μA, which can be varied by changing the separation of the plates. (A bit of salt in the water may help if it is too clean.) In fact, substituting a boy for the water, holding one plate in each (wet) hand will generate a few microamps. If you have a 0 - 100 μA ammeter, good fun can be had by letting the boys take turns to see who is the "best battery". There is generally enough variation in the wetness of their hands, and in oxidation layers on different parts of the plates, to cause substantial variations in the resulting currents.

If a multi-plate battery is built up of about 4 6" x 6" sheets of copper (all in parallel alternating with 4 of zinc or (new) galvanized iron (also all in parallel), submerged and separated only by tongue depressors to bring them as close together as possible, a 60 mA bulb can be lighted feebly. Cleaning the metal sheets of oxide in advance with steel wool will help.

6th Day. More circuitry; Coil winder.

Number	Supplies per boy	Total Cost	Supplier
	1. D-Cell Lantern		
1	D-cell	.08	OLS
1	Flashlight bulb socket, screw base (25F451)	.23	NEW
1	GE 123 flashlight bulb for 1 D-cell	.20	
5	2 - conductor miniature speaker cable (#24 stranded		
1	4 1/2" x 4 1/2" sheet of aluminum, about .02" thick		
12"	Coat - hanger wire		
1	SPDT slide switch (57F818)	.16	NEW
	2. Hidden Magnetic Reed Switch Game		
1	D-cell	.08	OLS
1	Flashlight bulb socket, screw base (25F451)	.23	NEW
1	GE 123 flashlight bulb for 1 D cell	.20	
1	Styrofoam block, about 1" x 3" x 5"		
1	SPST magnetic reed switch (e.g. 18A1433)	5/$2.00	BA
1	Strip of sheet iron (e.g., galvanized), 1" x 1 1/2"		
1	Strip of sheet aluminum, 1" x 1 1/2"		
1	1/8" x 3/16" x 7/8" break-off bar magnet	.05	AMP
	3. Coil - Winder		
1	Sheet medium-weight (about 0.02") galvanized sheet iron, 2 1/2" x 4"		
1	Tongue depressor		
2"	1/4" x 3/4" pine molding		
2	3/16" or 1/8" round-head stove bolts, 1", & nuts	.10	
1	2" x 1/4" hexagonal - head bolt, with 3 nuts	.10	
1	Heavy-walled plastic straw, 5/16" diam.		
3	Iron washers, 3/4" OD, 5/16"ID	.05	
2	Fibre washers, 1/2" OD, 1/4" ID (35F501)	.02	NEW
9"	Pine 2" x 4"		
14"	1/4" x 1 1/4" pine slat		
1	Nut for a 3/8" diam. bolt		
1	3/4" lead-pencil stub		

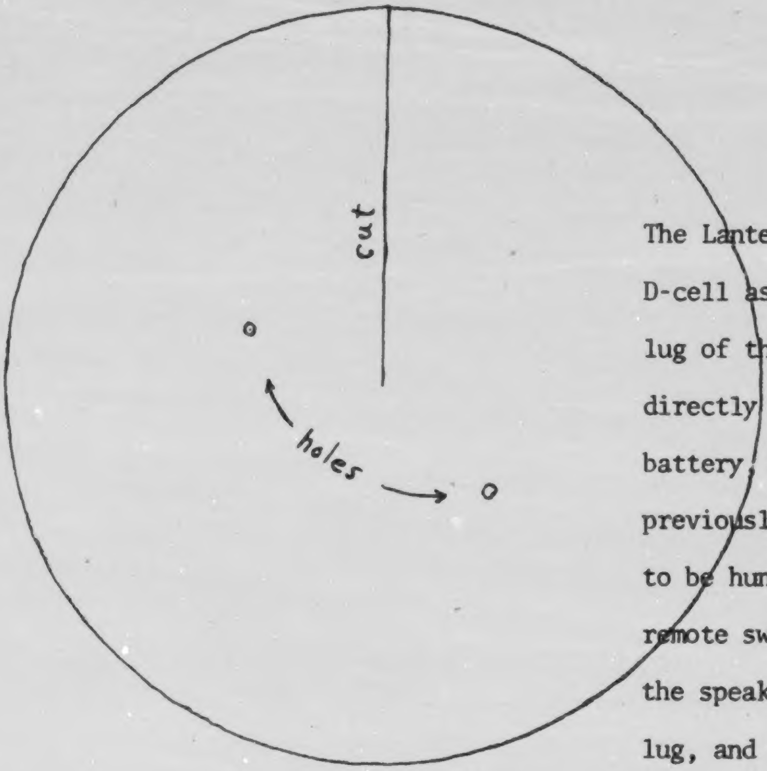
General supplies: 5/16" metal bit, and long-taper metal-reamer, for 1/4" and 5/16" holes (NEW 34550, $1.70).

Remarks: The ideal straw to use as a coil-form is a 5/16" diam. plastic one about 8" long. It has exceptionally heavy walls (usually white with a red "peppermint stripe"), and is obtainable (with a bit of persuation) from Dairy Queen ice cream shops, who use it as a push-handle for a popsicle-like confection called a "Mr. Misty Kiss". A usable alternative is the large-size (5/16" diam.) plastic malted milk straw obtainable from any soda fountain for a penny or so apiece. It has a thinner wall and is subject to collapse when wound, but it can be wound successfully if the first layer of wire is wound on with care. These straws are the perfect size to accommodate a 1/4" diam. magnet. For a 3/16" diam magnet, the 1/4" plastic straws obtainable from grocery stores are a bit, though not a great deal, better.

Hamlin has magnetic reed switch "seconds" available for about 15¢ but only in $25 lots. We may attempt to keep a supply on hand at the Physics Department, University of Wisconsin, Madison, Wisconsin 53706 (c/o McVoy). The normal price of Hamlin's cheapest model (MMRR - 2) is $1.84.

1. D-cell Lantern.

Another "fun" project, which may prove useful to boys whose bedrooms are very dark at night.



The Lantern is constructed with the D-cell as its body, as pictured. One lug of the bulb socket is soldered directly to the center part of the battery, as for the flashlight built previously. To permit the lantern to be hung near a bed, etc., with remote switch, solder one lead of the speaker cable to the other socket lug, and the other lead to the bottom of the battery; the slide switch (used as SPST) goes on the other end of the cable. The reflecting "roof" is cut from a sheet of aluminum with snips according to the pattern given, with holes punched slightly undersized (with a nail) to provide a friction-fit on the coat - hanger - wire handle, which in turn is taped in place. The whole is made slightly neater by sliding a section of toilet-paper roll over the battery, tied or taped in place.

2. Hidden Magnetic Reed Switch Game.

Magnetic reed switches (magnetically-actuated relays) are extremely useful devices, and this makes a nice introduction to them. Perhaps it's a good idea first to put one in series with a test lamp and D-cell, and let the kids practise turning it on and off with a small break-off bar

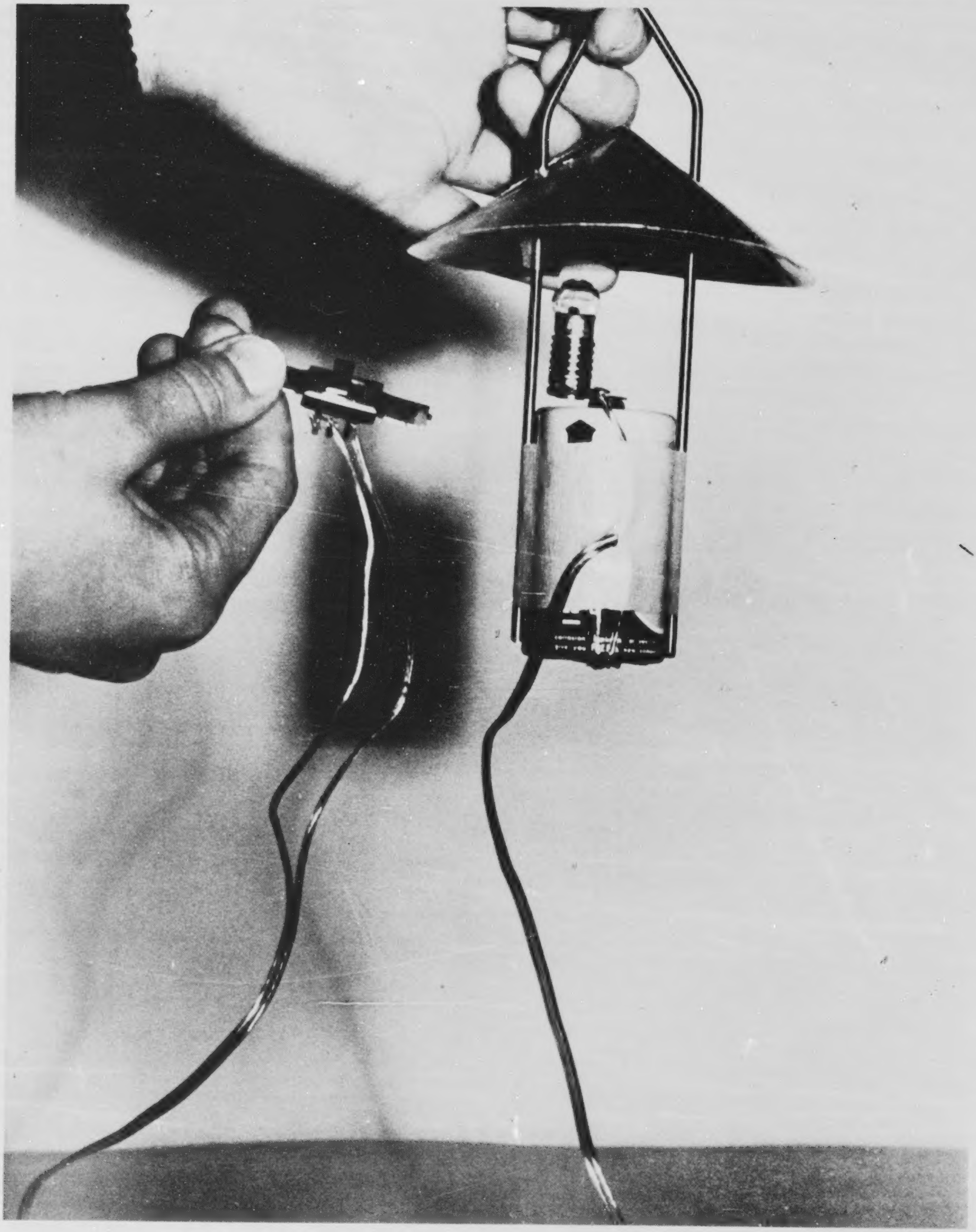


Fig. 5 D-Cell Lantern

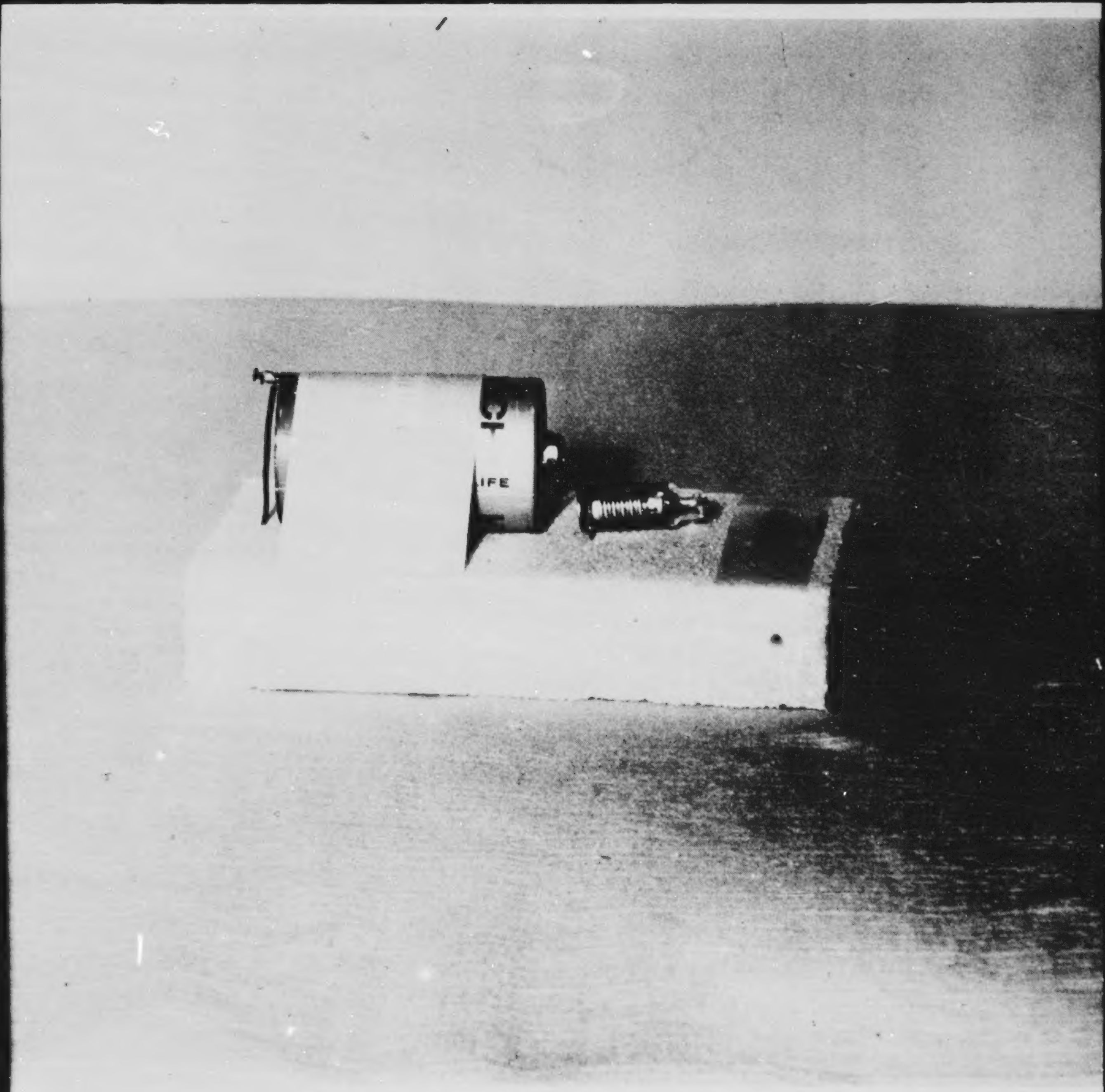


Fig. 6 Hidden Magnetic Reed Switch Game

magnet, to discover that it can be actuated from the greatest distance when the bar magnet is parallel to the axis of the switch.

The point of the "game" is to hide a reed switch inside a piece of styrofoam, close enough to the surface that a magnet placed on the styrofoam above it will close the switch, which then turns on a flashlight bulb (via hidden leads). The "game" is to get friends to guess how it works. It's even more intriguing if the magnet is taped permanently in place, and a slot carefully cut into the styrofoam between it and the switch, into which a strip of sheet - iron can be slipped to shield the switch and thus turn it off. The final elaboration is to have two such strips, as identical as possible, one of aluminum, which has no magnetic shielding properties; your iron strip will turn off the lamp when inserted, but the aluminum one, given to your friend, will not!

Although the device could almost as easily be built on a block of wood, or in a cigar box, etc., we found styrofoam easy to work with. A nail of the right size, used carefully, will punch a transverse hole for the reed switch, whose ends can afterwards be taped or plugged with other bits of styrofoam. The bulb socket lugs, after wiring on leads and running them through to the bottom of the block, can simply be forced into the block. The battery can be held on with masking tape or rubber bands. The only critical dimension is the distance between the magnet and the switch inside the block, which must be small enough to actuate the switch and large enough to slide the metal strips in between. Determine it by experimenting with your switch; 1/4" worked well with ours, which were Hamlin switches, MMRR - 2.

3. Coil-Winder for Electromagnets.

The boys will be winding many coils over the next few weeks. The job can be greatly facilitated by constructing a simple bracket which will enable them all to wind at once, and which can eventually be taken home, where it may encourage the boys to wind more as they need them for new projects. It is designed for winding on a 1/4" bolt, and on a 5/16" plastic straw.

The winding bracket itself, shown in Fig. 7, is made from a medium weight (thickness about .02", or the thickness of a pin) piece of galvanized-iron sheet metal, 2 1/2" x 4". First drill two holes near one end, about 1" from each other. For one use a 1/4" drill, with the hole centered 3/16" from the end of the metal, and for the other a 5/16" bit, with the hole centered 1/4" from the edge of the metal. A long - taper metal-reamer (NEW 34F550, $1.70) is almost essential for reaming the holes round and enlarging them to about 5/32" and 11/32" diam. The crucial dimension of the bracket is the distance between the two sides of the U-shaped bracket. It must be large enough to accommodate a 2" x 1/4" hex-head machine bolt as shown, with about 1/8" to spare when the first nut is screwed tight to

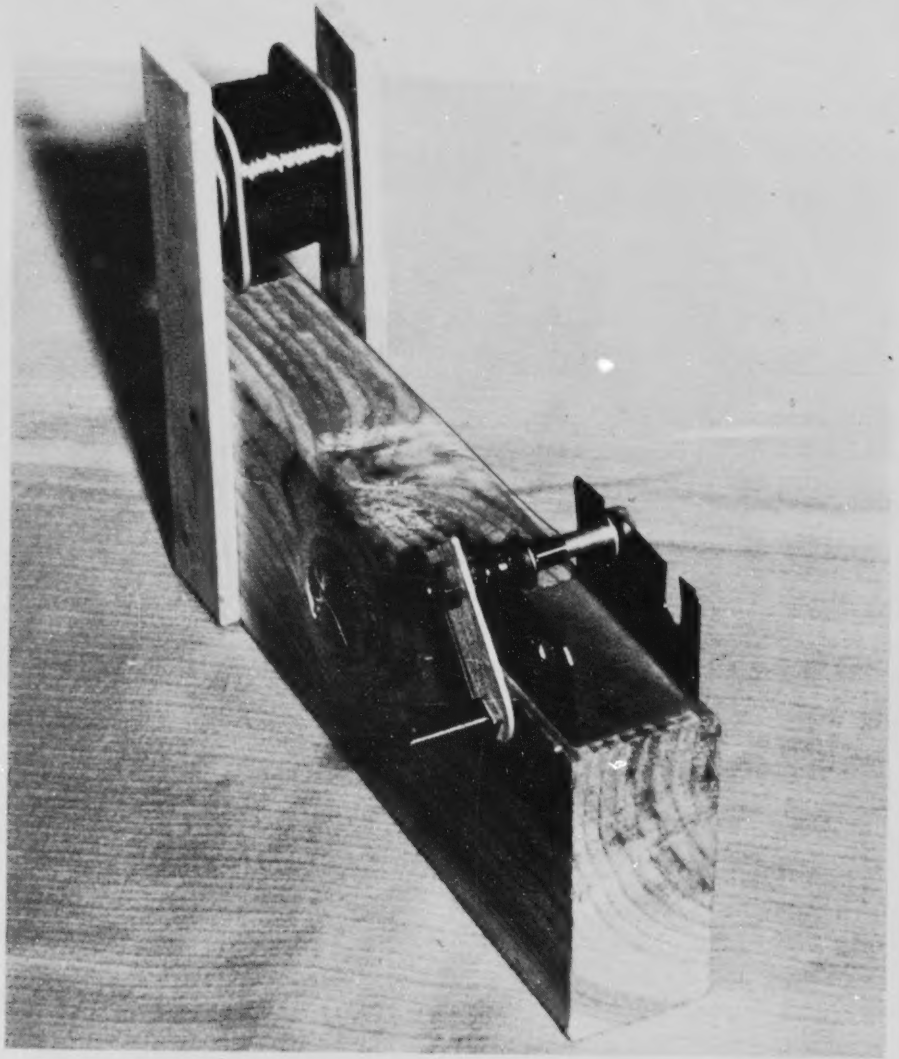


Fig. 7a Coil Winder, with Bolt

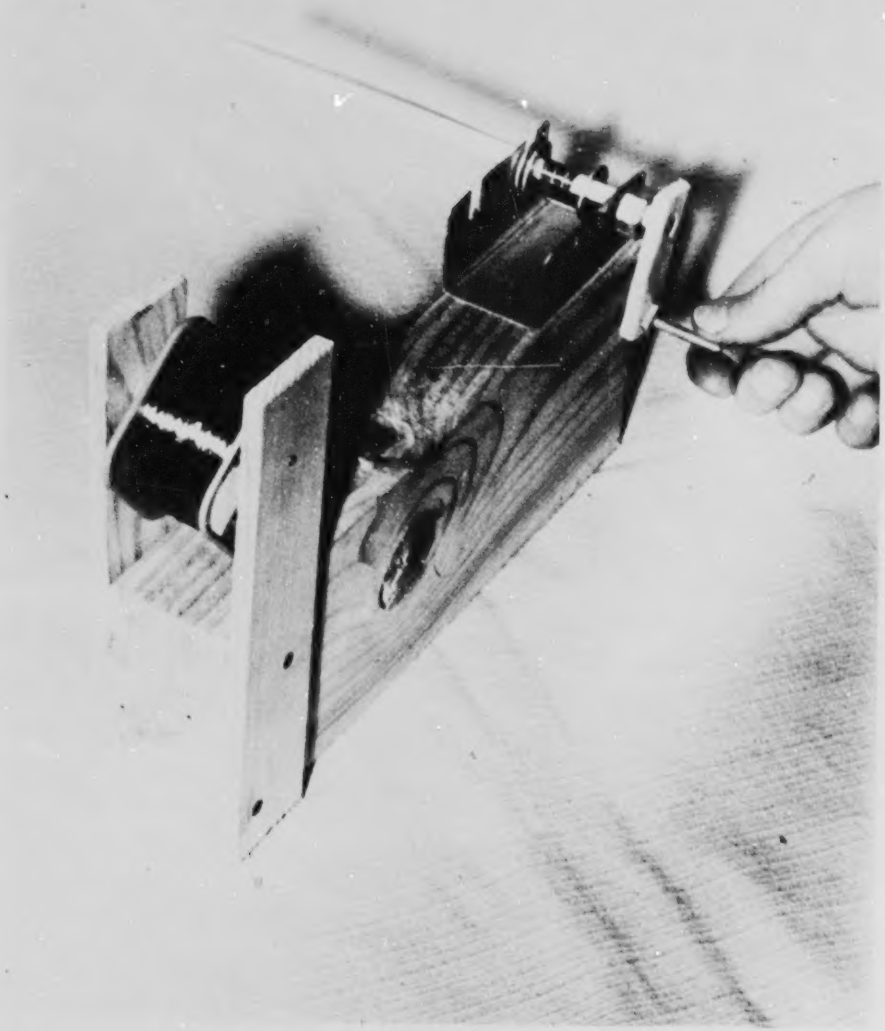


Fig. 7b Coil Winder, with Straw

the end of the threads; for most such bolts this requires about 1 5/16" between the two channel sides. After bending the channel to this dimension, drill the two holes in the second leg (again 1/4" and 5/16") by drilling through the first holes as guides. After these second holes are drilled and reamed, trim the height of that side to put these holes the same distances in from the top edge of their side as were the first holes, and cut vertical channels to them. The one to the 1/4" hole should be exactly as wide as the hole, while that to the 5/16" hole should be a bit narrower than the hole, to help keep the straw in place while winding.

Two crank handles are needed. That for the bolt should be made from 2" of tongue depressor and a 1" x 3/16" or 1/8" round-head stove bolt, with nut. The tongue depressor has a 1/4" hole at the opposite end for the coil-bolt, and is held in place on it between two extra nuts. The other crank is made from heavier wood; a piece of 1/4" x 3/4" molding works well. It has the same 1" bolt as handle, and also a 1/4" hole, this time for a 3/4" stub of lead pencil. If "sharpened" very slightly at both ends, the pencil can be forced tightly into this hole and also inside the straw. It fits snugly in the Dairy Queen straw, but must be wrapped with a bit of paper to fit tightly in a malted milk straw. A nut for a 3/8" bolt makes a useful spacer if slid on the pencil-stub under the handle.

In using the device, the winding must always commence a few inches from the end of the wire, to leave a lead for future connections. In the case of the bolt, these few inches can be wrapped carefully around the bolt between the inside nut and a washer which is also inside the winder channel, to keep it out of the way while winding. (A bit of tape will hold the wire in place for starting.) With the straw, two washers can be used at one end of the coil, inside the bracket, and the extra wire wound on by hand between them. Washers should always be used at each end of the coil, to avoid scratching the enamel insulation of the wire. For the straws, the standard 3/4" outside-diameter iron washers available from hardware stores have just the right inside diameter (5/16") while for the bolts, Newark's fibre washer #35F501 (a penny apiece) has the correct inside diameter, and an outside diameter of 1/2". Heavy paper or cardboard washers can of course be hand-made in a pinch.

If the boys are given individual spools of wire, it is especially convenient to mount the winding bracket on the edge of a 9" piece of 2 x 4, as shown (the spool rides on a 3/4" or 7/8" dowel); the 2 x 4 can be held between the knees for winding. The trick of using it is to allow the (enamelled) magnet wire to run between thumb and forefinger to maintain proper tension; a slight downward pressure on the wire will keep the bolt or straw from "riding up" in its slot, if the wire is always wound over the top of the bolt or straw.

When winding from a spool, the only way to measure the amount of wire on the wound coil is by counting layers, and this is accurate only if the layers are wound as smoothly as possible, without gaps or "criss-crossing". If this is done, and if the length of each layer along the bolt is 7/8", each layer will wind on 3 1/2' of #26 wire, so 12 layers will give the 42' coil (about 1.8 ohms resistance) used for most projects. Similarly if the length of the straw coil along the 5/16" straw is 1 1/8", each layer will wind on 5 1/2' of #26 wire, so 8 layers will give a 44' coil.

If the number of layers is even, twist the two end-leads together, and if odd, tie the loose one in place with a half-hitch. Running a bit of airplane cement over the coil, or wrapping it with masking tape, will keep it in place, especially the straw-wound one, which tends to ravel at the ends. For some projects, a shorter, fatter straw-wound coil is needed. Use more washers inside the bracket to limit its length, and wind one or two to see how much wire goes on in each layer.

7th Day. Electromagnets

Number	Supplies per boy	Total Cost	Supplier
	1. Nail Magnet		
1	2" common nail		
15'	#26 enamelled copper magnet wire		
1	D-cell	.08	OLS
1	SPDT (or SPST) spring-leaded micro-switch	.20	
1	Iron nut for 1/4" bolt		
1	Coat-hanger		
	2. Plastic-straw Solenoid		
1/2	5/16" diam. heavy plastic straw		
25'	#26 magnet wire		
1	6-penny brad (2")		
1	1" x 3/16" diam. Alnico bar magnet	.35	AMP

3. Telegraph Clickers and Buzzers.

1	D-cell	.08	OLS
1	2" x 1/4" hexagonal-head machine bolt & 3 nuts	.10	OLS
1	SPDT (or SPST) spring-loaded microswitch	.20	
1	2" x 4" x 7", pine or fir		
1	1" x 2" x 2 1/2", soft pine, #1 grade (clear)		
2	2" (6-penny) box nails (thin shank)		
3	8 x 1/2" pan-head sheet-metal screw		
2	6" strip of 1/2" band-saw blade, punched with two holes		

General supplies: Spray-can of electrical contact - cleaner.

Remarks: All the coils wound during the course will employ #26 enameled magnet wire (Beldsol). It is available in 1/2 lb. spools (645') from Newark (36F 1316) for $1.45, and each boy should receive one, marked with his name.

1. Nail Magnet.

As a simple beginning, wind 15' of #26 magnet wire by hand, on about a 10 - penny (2") common nail. Warn the boys to leave 5" of the beginning - end of the wire free as a lead, and to finish the coil with the two ends of the wire adjacent to each other, so they can be twisted together. Scrape the enamel off each end for 1/2" or so with a piece of sheet-iron. The battery is being practically shorted out with this small resistance across it, but the boys have no way of knowing this and tend to leave the magnet on, thus rapidly exhausting their batteries. Consequently all electromagnets should be used in series with a spring-loaded switch, (N.O.) such as a micro-switch. Power them with a single D-cell with short leads soldered in place; clip leads are useful.

Use the electro-magnet to pick up nails and paper clips as before, and bring two together to see that they have poles and so will repel in one orientation and attract in the other. Reverse the current of one.

A nice game can be made by suspending an iron nut for a 1/4" bolt (used later for a bolt-electromagnet) over the table on a thread, from a support made from a coat-hanger. Just below it the nail-electromagnet, driven vertically into a board or the table-top (if expendable), can be "pumped", to set the nut swinging. It can even be made a competitive game if desired, with a battery or micro-switch as a prize.

2. Use the coil-winders to wind 25' of #26 magnet wire on a 5/16" plastic straw. (Wind it "bunched together", to make the finished coil as short as possible. Friction-fit washers will help.) After winding, cut off the excess straw and use the coils (with the above D-cell) to "suck-in" a 6-penny brad, which is always an amusing effect. The coil also makes a nice cannon, which will shoot the 3/16" diameter magnet a few inches (the principle of gong-type doorbells); this has the makings of another competitive game.

3. Telegraph clickers and buzzers.

An excellent coil can be wound (using the coil-winder) of 40' of #26 wire on a 1/4" x 2" hex-head bolt, with the nut screwed down tight to the end of the threads. (When finished winding, save the 2 spare nuts for later electromagnets.) It can be used nicely with the thread-suspension of (1) above. If the bar magnet from (2) is taped to the thread in place of the nut, and the bolt held or fastened horizontally just below it, the magnet will be attracted toward the iron bolt even with the current off, and will leap toward one end or the other when the current is turned on. Reverse the current to see it jump the other way. Again, with the bolt fixed vertically (e.g., in the 2 x 4 below) below the magnet, the same pump-the-swing game can be played, but this time with much more force.

To build the telegraph clicker pictured, drive the bolt vertically into a 1/4" hole in a 7" piece of 2 x 4. (If a short piece of bare wire is twisted around the bolt-threads before driving them into the hole, it can be used later as a relay-contact) A 6" piece of 1/2" wide band-saw or hack-saw blade makes a good armature, but it cannot be drilled with hand-tools and must be machine-punched with two holes, 1/2" and 1 1/2" from one end, each about 5/32" diameter (to take a #8 sheet-metal screw). It is mounted on a 2 1/2" piece of 1" x 2" by a 2" box nail (thin) driven through the end hole and entirely through the (soft pine) 1" x 2", to fasten both to the 2 x 4, and by an 8 x 1/2 pan - head sheet-metal screw through the other hole. If the blade is bent upwards 20° or so between the two holes before mounting, the sheet-metal screw provides a convenient adjustment of the distance between the blade and the bolt-head. (In order to use the device as a buzzer later, it is useful to sandpaper some of the blueing off the top side, about halfway down the blade, before mounting it.) A D-cell held in place between the 1" x 2" block and a second nail, together with

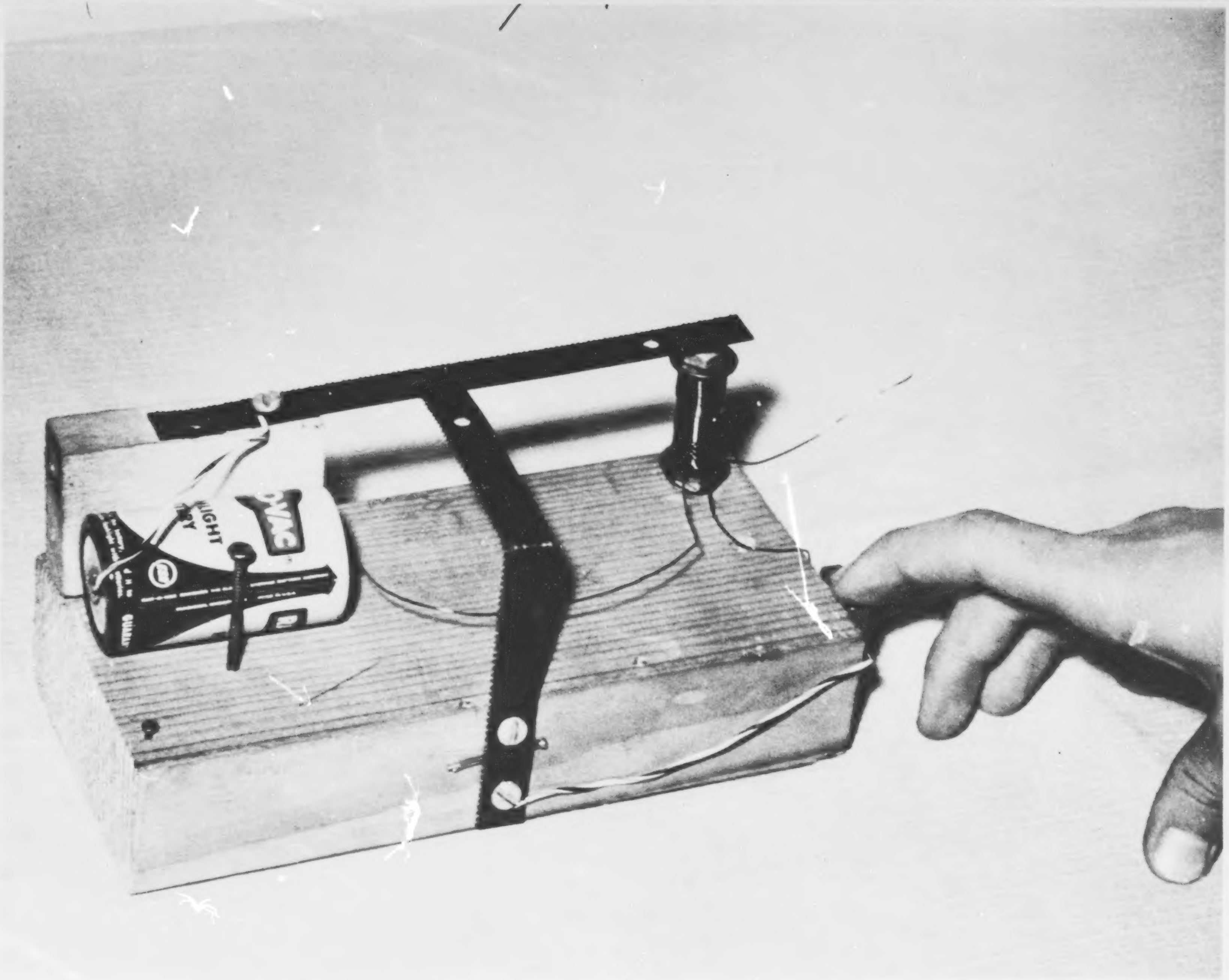


Fig. 8 Telegraph Clicker-Buzzer (with buzzer-arm attached)

a micro-switch nailed to the end of the 2 x 4 as a "telegraph key", complete the clicker. Again have a few copies of the International Morse Code available for the kids to copy onto the strip of masking tape and fasten to the clicker. By this stage it should be possible to show them a model without any wires on it, and let them figure out the circuit themselves.

Relays are something the boys should understand, and this clicker makes an ideal one, by attaching clip leads to the bolt and armature, so that they are connected together when the blade (which may need some sanding) hits the bolt. At the moment, they don't seem to have anything to turn on but a test lamp or the nail-electromagnet (using the other D-cell from #1 above). If you have any commercial relays, this is a good time to demonstrate them.

Finally (although there may not be time to finish it today) the clicker can be converted into a buzzer by adding a second contact. To be sure the idea gets across, do it first by hand. Break the circuit anywhere, and connect one end of the break to the hack saw blade, for instance by sliding the wire under it or under the head of the sheet - metal screw. Put a clip-lead on the other end of the break and touch it also to the hack-saw blade, from above (an edge usually works best), near the free end. This closes the circuit through the blade, but as soon as the current flows, the blade is pulled away from the clip-lead. This breaks the circuit and releases the blade, which snaps back against the clip-lead, turning the circuit back on, etc., etc. The result is a nice buzzer.

To make a more usable buzzer, a permanent second contact needs to be added, which just touches the armature from above. This is shown in the picture, mounted on the side of the 2 x 4 with two screws. It is a second saw-blade, bent into an L-shape, with 1/2" of the upper tip bent down slightly to touch the clicker-armature. A small brad inserted under this second blade between the two mounting screws will allow the pressure of its contact on the armature to be adjusted by turning the upper screw. This pressure is very critical; both it and the gap between armature and electromagnet must be adjusted very carefully to make the buzzer work - a task made much lighter by spraying the contact - point between the two blades with contact - cleaner to prevent the arcing there from corroding the contact.

Incidentally, used as an oscillating relay, the buzzer can serve nicely to illustrate a principle which will help explain the operation of the loudspeaker later on. Connect the straw solenoid from #2 above, with its dry cell, in series with the bolt-and-blade relay, and hold the solenoid vertically, with a small brad or the 3/16" diameter bar magnet inside, resting on your finger. If it's in the right position, you should feel it vibrate when the buzzer is turned on, provided the armature is hitting the bolt-head to close the relay circuit. If a D-cell fails to drive the brad hard enough to feel, use two in series, or perhaps a 6-volt battery instead. Finally, rest the brad loosely on a convenient "sounding board", such as a thin cardboard box instead of the finger. Then when it vibrates it will produce an audible buzz, best heard if long leads are used to get away from the noise of the relay-buzzer itself. This is, of course, exactly how a magnetic speaker produces a tone. It is a good idea to save one buzzer, to repeat the experiment later with a commercial loudspeaker. Also, keep the straw solenoid and its bar magnet at least until tomorrow, for it will be needed in conjunction with a motor to be built.

8th Day. Simple Electric Motors.

One of the most important practical uses to which electromagnets are put is the operation of electric motors, and the next 2 days are devoted to building and using a variety of them.

Number	Supplies per boy	Total Cost	Supplier
	1. Reed Switch Motor		
1	2" x 4" x 6", pine or fir		
1	1/4" hardboard or pegboard, 3" x 4"		
1	2" x 1/4" hex-head machine bolt, and nut	.10	
40'	#26 enamelled magnet wire		
1	6" (60-penny) spike		
1	60mm x 15.8mm plastic (polycarbonate) test tube (647-0272)	.25	Cole-P
1	Metal washer, about 3/4" OD, 5/16" ID		
1	4" cardboard disc		
2	1 3/4" alnico break-off magnets	.20	AMP
1	SPST Magnetic reed switch (e.g. 18A1433)	.40	BA
1	Miniature alligator clip (28F528)	.05	NEW
1	D-cell	.08	OLS
1	3" piece of 1/2" band-saw blade, punched with 5/32" hole 1/2" from end		

2	8 x 1/2 pan-head sheet metal screws		
1	3/4" x 1" x 3" block of styrofoam		
6"	Twin-lead #32 phono pickup wire, very thin (36F158E)		NEW
1	Moore Toy Motor Kit (43597)	.50	STAN

General Supplies: Spray can electrical contact-cleaner, can light oil (slot-car oiler works very well).

Comments: The best test tubes for the motor are the clear polycarbonate ones listed, available only from the Cole-Parmer Co., 7425 N. Oak Park Ave., Chicago, Illinois 60648 (Tel. (312) 647-0272), for $2.76 per doz. If you are willing to use glass, the 75 mm x 10 mm size will do nicely, and is available from any scientific supply company for about 65¢/ doz.

1. Reed-switch-commutator Motor. This motor is designed to be as simple and transparent as possible, to get across the basic concept - a magnet pushing on a magnet - without confusing refinements.

Because it has very little power, a low-friction bearing is needed; the cheapest seems to be a plastic (to avoid breakage) test tube inverted over a 6" (60-penny) spike driven upwards through a 2 x 4 base. The test tube should not be longer than 3 1/4" in order to allow room for a 1" thick piece of styrofoam to be added later; if one this short is not available, a longer one can be sawed off. The motor will run smoother and faster if an ordinary iron washer (3/4" OD is fine) is glued across the open end of the test tube as a lower bearing.

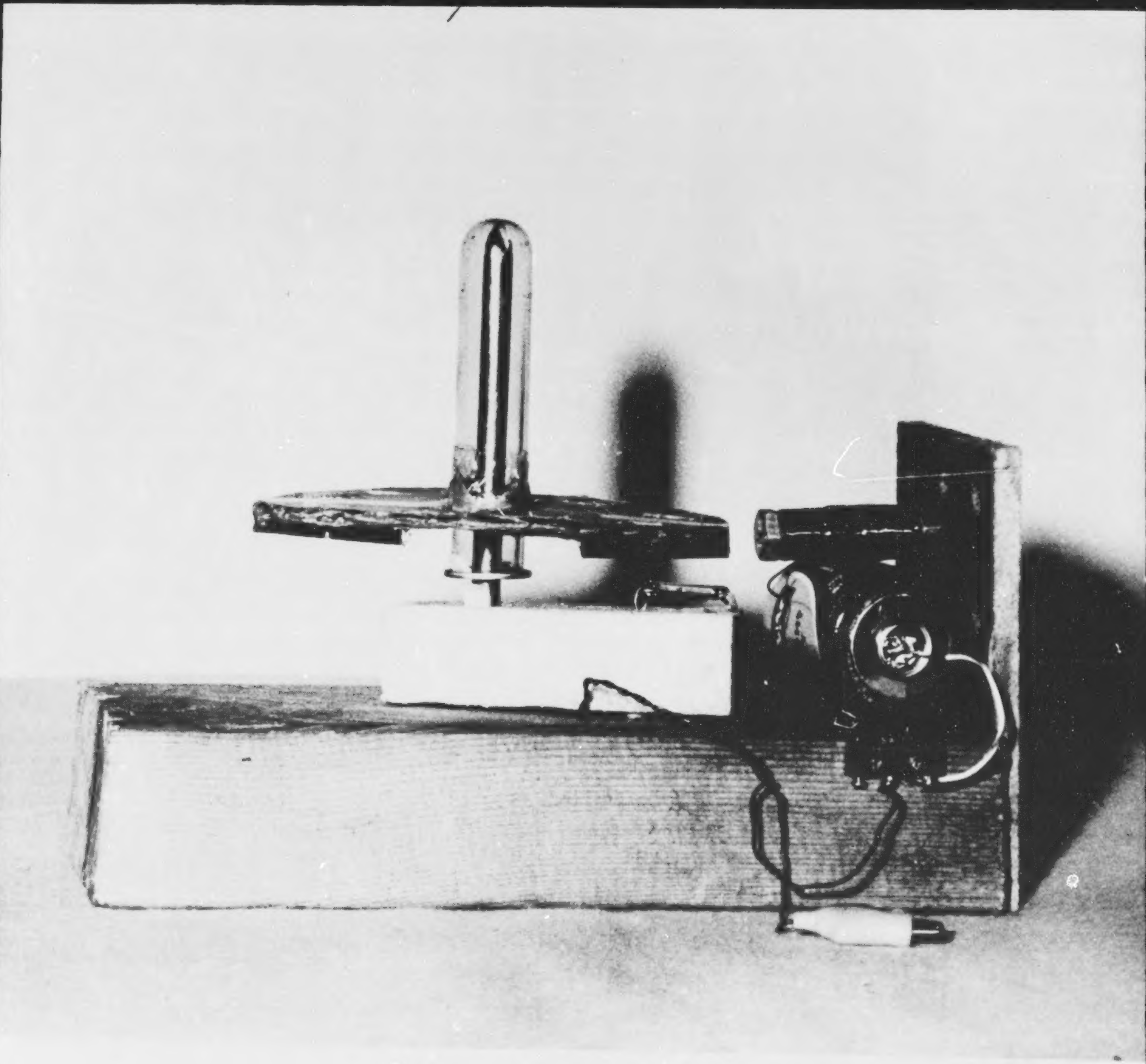


Fig. 9 Magnetic Reed Switch Motor

The base should be drilled for the spike with an undersized bit, to avoid splitting, and it even helps to pre-drill it from the bottom about 1/16" with about a 1/2" bit, to countersink the spike-head. The "armature" is a 4" disc of cardboard (ordinary corrugated box material is fine), which could be cut by hand but is neater if done with a circle-saw or similar device. (1/8" or 1/4" sheet-styrofoam would do equally well, and even a tongue-depressor could be used if the small (10 mm diam.) glass test tubes were employed.) A cross is slit in its center, and the disc pushed over the test tube. Two 1 1/2" break-off bar magnets are taped to its underside, at opposite ends of a diameter, with similar poles pointing outward.

Another 40' coil of #26 wire is wound on a 2" bolt, which is screwed into a 1/4" hole drilled into a 3" x 4" piece of 1/4" hardboard, and this in turn is nailed vertically to the end of the base. If the bolt-magnet is mounted just the right distance above the base, it will hold the D-cell in place underneath it against the hardboard; otherwise a nail will do it. Incidentally, the position of the center spike should be chosen so that the disc edge just misses the head of the bolt when the bolt is screwed halfway into the hardboard; this allows it to be screwed either way later for fine adjustment. (Because the boys will saw the ends of their 2 x 4's at various angles, the position of the bolt-head will vary from one boy to the next. Consequently it may be safest to drill for the center spike after the hardboard and bolt have been attached to the 2 x 4.)

Because the permanent magnets are attracted to the iron bolt, the equilibrium position of the disc is with a magnet opposite the bolt. If the coil is given a pulse of current in the direction which repels the permanent magnet, the disc will begin to rotate, and coast, bringing the next magnet opposite the bolt. Another appropriately - timed pulse will push it faster, etc. In other words, it is a primitive motor in which the operator does the commutating by hand. A microswitch works beautifully here, but in order to give the boys practice in building their own switches, it might be a good idea to use instead a "telegraph key" made of a 3" slightly-bent length of band-saw blade (pre-punched with a 5/32" hole 1/2" from one end) screwed to the base with an 8 x 1/2 sheet-metal screw, with another such screw as the lower contact.

This motor will rapidly pick up more speed than hand-commutating can accommodate, making the necessity for automatic commutating abundantly clear. An extremely elegant solution to the problem (devised by Ross Henderson) is to use a magnetic reed switch, actuated by the rotating permanent magnets. A simple mounting is provided by soldering wire leads (very thin phono-pickup wire) to the end-leads of the reed switch ("backwards", with the ends of the phono-lead and switch lead pointing in the same direction), then bending each switch-lead 90° (do not hold the switch by the capsule while bending; hold the lead near the capsule with needle-nosed pliers) and pushing these parallel leads into a block of 3/4" thick styrofoam. (This applies to the Hamlin switches, which have long leads. Those on the BA switches are too short to bend, but the switch can be taped to the styrofoam block.) If the styrofoam is carefully pushed down over the nail, it will hold the reed switch in a horizontal position below the rotating magnets. Rotating the mount about the nail changes the phase of the magnet pulse relative to the bolt, which can be adjusted for maximum speed. Rotating the switch to the other side of the bolt will slow down the motor and eventually reverse it.

The change from hand to automatic commutating can be made conveniently by putting the two switches in parallel, with an alligator clip on the end of one lead from the reed switch. With it connected to one end of the hand switch, both switches are operative, and with it disconnected only the hand switch is. Incidentally, it is a good idea to put a test lamp in parallel with the electromagnet coil (have the boys draw the circuit!), to see exactly when the switch is turning on, and to check that both magnets are in fact actuating the switch each time around.

Another very nice way of doing the same thing is to use the straw-wound solenoid coil which was made on the 7th day. Put it in series with the electromagnet coil of the motor, with its bar magnet inside the straw. This will cause the bar magnet to hop up each time the reed switch goes on. The straw can be conveniently mounted vertically by drilling a hole of appropriate size (5/16" for the plastic straws) lengthwise in a 1" diameter dowel, and then sawing off a "doughnut" slice and gluing it down to a piece of cardboard. The straw can be inserted into the hole, and the bar magnet tapping against the cardboard makes another good analogue of a loudspeaker.

These motors should not be sent home yet, for they will be used in a few days in connection with loudspeakers. After labelling each with the boy's name, collect and store them.

2. The second motor to be built is the nice little "Moore Toy Motor" available commercially as a kit from Stanci, for instance. It uses conventional brush commutators, and it is much less easy for the boys to follow the circuit (perhaps having them draw it out and paste it inside the base after building the motor would be a good idea), but once adjusted it buzzes along in delightful fashion. Although the motor is cheap, the project is a bit expensive because the motor requires more current than a D-cell will provide, and will only operate reliably on a large No. 6 ignition cell.

Because the instructions are quite complicated, it is wise to xerox off extra copies and send them home for study a day ahead. For all its attractiveness, the Moore motor can sometimes be a demon to get operating; light oil on the bearings and liberal quantities of contact cleaner sprayed on the brushes will help. To avoid shorts, it's not a bad idea to put tape around the armature-slug before winding the armature coil on it, and around the axel underneath the rotating "brushes".

A device as intricate as this one needs close supervision, and is best built with the boys working on their storage box tops, placed in a large circle on the floor. All can then do each step together and have it checked by instructors before proceeding to the next one. Incidentally, because the devices sent home are now becoming quite fragile, this is an excellent time to send the storage boxes home.

9th Day. Applied Motors: Hoisting Crane with Reversing Switch.

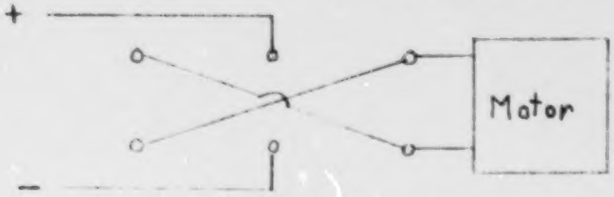
Number	Supplies per boy	Total Cost	Supplier
	2. Hoisting Crane		
1	3V. slot-car motor, e.g. Russkit 34 (SL-59)	.25	OLS
1	Strip of sheet aluminum, 1" x 4"		
2	D-cells	.16	OLS
1	DPDT knife switch, with round-head mounting screws (19A7022)	.48	B-A
1	2 1/4" diam. x 1" thick styrofoam "wheel"		
1	5/16" dowel, 3 1/2" long		
1	Rubber band (live rubber); heavy thread; paper-clip hook.		
1	2" x 4" x 9", pine or fir		
2	Slats, 4 1/4" long		
1	1/2" dowel, 10" long for boom		
1	Small (1/4" diam.) screw-eye.		
6"	1/2" band-saw blade, with hole punched 1/2" from each end		
1	SPDT micro-switch (18C256) (optional)	.49	BA
1	3/16" diam. x 1" alnico magnet	.20	AMP
1	Small (1" x 1") square of 3/32" thick balsa wood		
1	2" length of 5/16" or 1/4" plastic straw		
30'	#26 enamelled magnet wire		
6'	2-conductor phono pickup wire (36F158E)		
1	SPST or SPDT microswitch	.20	

This particular motor is particularly attractive because it is cheap (4/$1) and powerful. If it should happen to be out of stock, alternative motors are (18B379) from BA, 12/$3.49 or 3/99¢, or (MO-169) from Olson, 4/$2. They are less powerful, and will either need 3 D-cells or a 1 1/2" diam. styrofoam wheel on the hoist in place of the 2 1/4" one. If the boys do not have potentiometers, some chromel wire will be useful as a speed regulator.

1. Trying out the motors. A few minutes of play with the motor alone is a good idea, to see that it often won't start on a single D-cell, and that its speed can be controlled with a potentiometer (about 5Ω) in series if the boys have them, or with a piece of chromel wire and a sliding contact. The fact that the motor draws more current when carrying a load can be shown by putting one of the GE #14 (3V) lamps in parallel with it; the bulb will dim as the load increases, because the resistance (actually inductive impedence) of the motor decreases, causing more of the current to flow through the motor arm of the parallel circuit and less through the bulb. (Unfortunately this can't be done by putting the bulb in series with the motor, which is an easier circuit to understand. The motor resistance is so low that most of the potential drop occurs across the bulb, and the remainder is too small to start the motor.) If this is hard for the boys to understand, put a 5-ampere ammeter in series with the motor to read the current directly; the starting and heavy-load current is around one ampere (which is a warning not to leave the motor running unnecessarily).

The boys will discover soon enough that the spinning gear on the motor makes a fine engraving tool, which can be used to scratch their names on their tool boxes, and that a stick (e.g., a ruler with a hole in its center) can be jammed over the gear to make a helicopter-blade. Try reversing the battery leads to see that it reverses the motor direction, and explain why.

It is probably a good idea to have the boys wire up the DPDT knife switch as a reversing-switch before starting on the rest of the hoist.



2. Hoisting Crane. As for the hoist itself, its special features are great strength and low speed, reversibility, and a limit-switch to shut it off when the thread is wound up. The latter is a microswitch mounted at the end of the base, exactly flush with its top, with the band-saw blade mounted to depress the switch unless the hook at the end of the thread bends the blade and releases the switch. It may be necessary to use a sheet-metal screw near the switch to hold down the blade strongly enough. (The knife switch must be reversed to unwind the thread, but of course the motor will not start until the microswitch is depressed by pushing on the band-saw blade). If the microswitch is too expensive, the band-saw blade itself makes a perfectly good switch, with a sheet metal screw as the lower contact.

The motor is fastened down with a strap of sheet aluminum and two small nails. A rubber band around its shaft (kept on by the gear at the end of the shaft) drives the styrofoam wheel. The wheel is cut from a 1" sheet of styrofoam with a circle saw (from both sides if necessary) and held in place on the 5/16" dowel axel by drilling a hole through the axel and inserting a nail through both wheel and axel. The axel bearings are small box nails inserted through drilled holes in the slats and driven into the ends of the axel. The sturdiest boom is made by drilling a slanted 1/2" hole in the base (with a power drill; this should be the first step in building the crane) to insert the 1/2" dowel boom. The 5-ohm pot handed out on the 5th day is ideal for controlling the motor speed. Let the boys figure out how to use it.

It will help if the rubber bands for all boys are the same, so that they can all use the same motor position relative to the styrofoam wheel.

After using the crane with a simple hook for a while, one nice addition is a magnetic lifter, for picking up paper clips, nails, etc. To avoid having an electromagnet on for long periods, one approach is to wind a coil of 30' of #26 magnet wire on a plastic straw 2" long (bunched, to cover only about 1/2" of the straw). If to this is glued at one end, a "cap" of a 1" x 1" square of balsa wood (for instance), and a

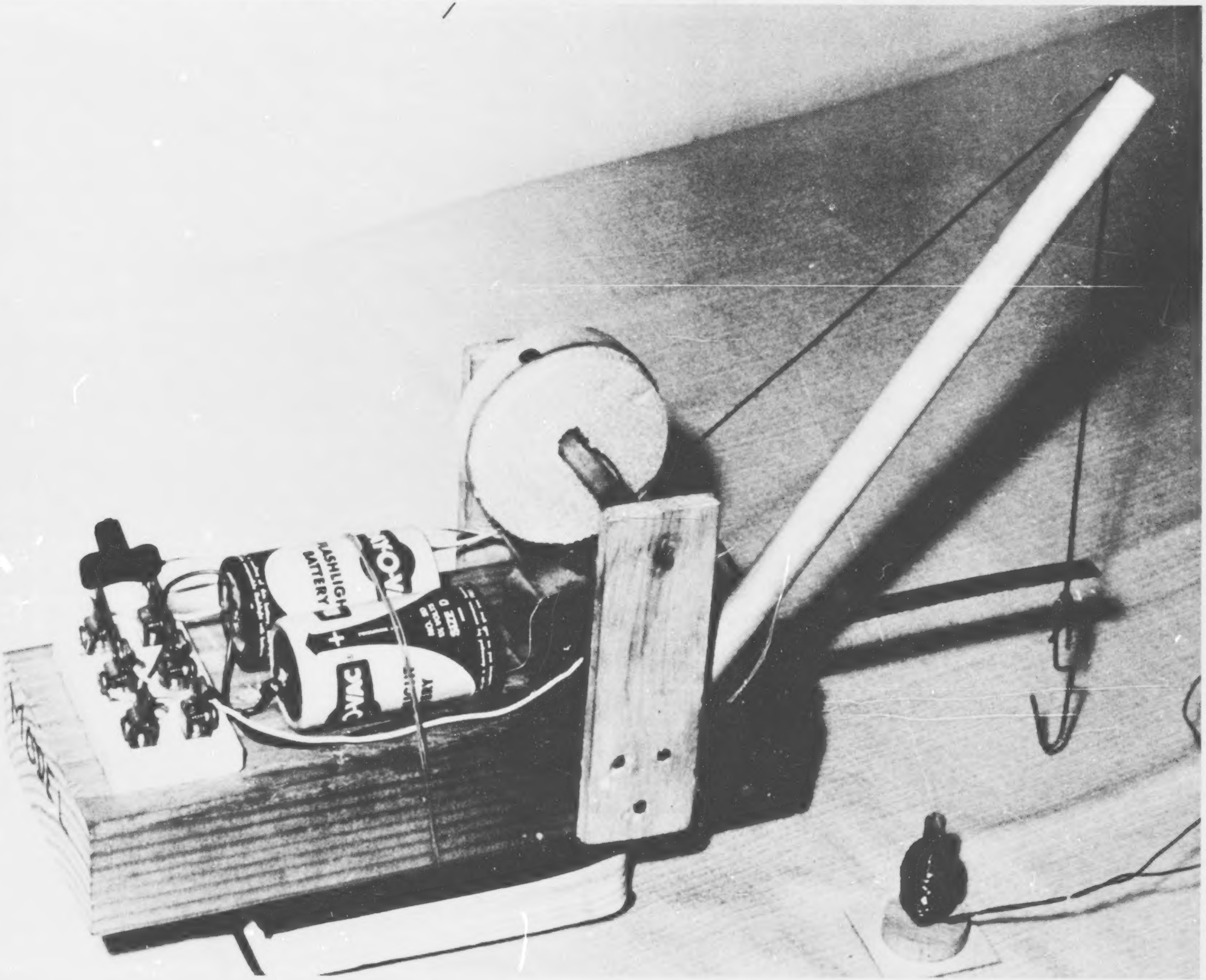


Fig. 10 Hoisting Crane, with Electromagnetic "Lifter"

3/16" diam. x 1" bar magnet is inserted into the straw, the magnet will pick up paper clips, etc., right through the end cap. A pulse of current through the coil will lift the magnet away from the cap and allow the load to fall off. The thickness of the end-cap is quite crucial, for if too thin the load will not release. 3/32" seemed ideal for our magnets, but this should be tested in advance. By far the best leads are the very flexible phono pickup wire; since the device is used only briefly (a second microswitch is convenient for it), it can use the same batteries as the motor, in parallel with it (but not using the reversing switch!)

It can of course be used with a single hoist, and the boys can compete in moving piles of paper clips from one location to another. Much more fun can be had by hanging a lifter from three hoists simultaneously, positioned 120° apart on separate tables or chairs. (The hoist limit switches cannot be used in this case). In this way, the three boys on the hoists can cooperate to lower the lifter over a pile of paper clips, lift them, and move them to a different location. Two or more such teams can set up an exciting competition.

There are doubtless many more uses to which the hoist can be put, such as operating a cable car, pulling a curtain open and closed, operating a pile-driver, etc. If you have the time, this is an excellent time to give the boys a chance to use their own imagination for a change, rather than just following directions. Remember, though, that they have been exposed to a great many new and undigested ideas during the past few days, so don't be disappointed if they seem to show a lack of interest in experimenting and improvising on them. They may simply be completely bewildered, but are too shy to admit it.

Toss out as many ideas as you can, to encourage different boys to try different things, and keep some of them extremely simple, like putting a "warning light" in parallel with the motor, which will go on when the motor is turned on; a test-light works fine. (Let them also try it in series with the motor, if they wish; most likely the large resistance of the bulb will cut down the current to the point where the motor won't operate at all.) Competition does wonders for the imagination in situations like this; try suggesting a few competitive projects to stimulate the better boys into action.

10th and 11th Days. Sound, Microphones & Loudspeakers.

Number	Supplies per boy	Total Cost	Supplier
	1. Paper Cup Telephone.		
2	Paper drinking cups, as heavy and stiff as possible	.05	
50'	Heavy string	.15	
	2. Paper Cup Loudspeaker.		
1/2	5/16" diam. heavy plastic drinking straw		
25'	#26 magnet wire		
20"	#18 soft copper wire, bare (NEW 36F702)		
1	1/4" diam. x 1" alnico bar magnet	.35	AMP
1	Cold-drink paper cup with thin bottom ("Solo" brand is good)		

1	D-cell	.08	OLS
1	2 1/2" PM speaker, 8-10Ω, square yoke (S-641)	.44	OLS
15"	2-conductor miniature speaker cable, #24 (36F105)		NEW

3. Carbon - Rod Microphone

1	1-pint thin-walled plastic food container, with friction cover	.10	
2	1/2" x 1" strips of 1-mil shim brass (machine shop)		
4"	2-conductor phone pickup wire, #32 gauge (36F158E)		NEW
1"	3/16" diam. carbon rod, 12" long (5914-10)		WEL
75'	2-conductor miniature speaker cable, #24 gauge (36F105)	.75	NEW

4. Two - Way Telephone

2	1/4" hardboard or pegboard, 4" x 6"		
2	D-cells	.16	OLS
1	2 1/2" PM speaker, 8-10Ω, square yoke (S-641) (for other speaker use that from #2 above)	.44	OLS
15"	2-conductor miniature speaker cable		
2	Carbon-grain microphones (M - 135)	.50	OLS
4	4" lengths of pine slat		
4	8 x 1/2" pan-head sheet metal screws		
2	1/2" band-saw blade, 3" long, hole pre-punched 1/2" from end		

General Supplies: Ripple tank (with wave generator and appropriate illumination) and 2 or 3 tuning forks (perhaps two which will beat against each other), both of which it should be possible to borrow from a nearby high school. Several metal files (a saw blade will substitute if necessary) two transistor radios with earphone cords. The Stansi bell-in-a-jar apparatus (#41423, $9.10), together with a vacuum pump borrowed from a high school. Needs a 6V lantern battery ($1.50).

1	CdS photocell (20A22)	.99	BA
1	9-V transistor radio battery (BA-89)	.20	OLS
1	GE #48 flashlight bulb (2V, 0.06A) (27F122)	.14	NEW
4	3V slot-car motor, Russkit 34 (SL-59)	1.00	OLS
1	4" cardboard disc		

The thin-plastic food container for the carbon-rod microphone should be obtainable from the delicatessan or butcher department of a grocery store. The soft copper wire for supporting the coil on the paper - cup loudspeaker, NEW 36F702, is a 100' roll for $ .86. The carbon rods from Welch (5914-10) are sold 12 for $1.85.

1. General Ideas. Have the boys listen to a vibrating tuning fork, and at the same time feel it vibrate (against finger or ear). Making it "buzz" against a piece of paper, and spatter in a pan of water (notice waves moving out from it) are also useful to show that it actually is vibrating.

If a ripple tank can be borrowed from a nearby high school, it provides an excellent means of illustrating wave propagation and reflection. (The PSSC tank requires a much smaller light source - for casting wave shadows - than an ordinary light bulb; a mask with a small hole will work, but a non-frosted bulb with a small filament is better.) However, the boys have often already seen a ripple tank in school, and may consider it supremely dull because it seems so impractical to them.

Much more fun is building stretched - string telephones by passing the ends of 50' of strong string through holes in the bottoms of sturdy paper drinking cups (preferably the hot-drink type) and knotting them. Tin cans will of course also work.

2. Paper-cup loudspeaker. Wind another coil of 25' of #26 wire on a plastic straw, and cut off the straw to be 1 1/2" or so long, with the center of the coil about 1/2" from one end. The coil should be bunched, to make it as short as possible. Use two pieces of heavy (#18) copper wire (which is flexible, strong and non-magnetic), each about 8" long, to wrap around the body of the coil as "spider legs", which are taped to the sides of a cold-drink paper cup, with the short end of the straw suspended 1/8" to 1/4" above the bottom of the cup. (The cup-bottom is the diaphragm and should be as thin and flexible as possible. "Solo" brand cold-drink cups are good.) Put a small drop of glue on the end of a 1/4" diam. x 1" alnico magnet and drop it through the straw to glue itself to the cup bottom; avoid getting glue on the inside of the straw. The other end of the magnet should project about halfway inside the coil for highest efficiency.

Using a single D-cell, listen to clicks when the circuit through the coil is closed and opened. Put a metal file in series with it by scraping one lead along the file, to produce a buzz; changing the speed changes the pitch of the note. The same thing can be done nicely by mounting a fine wire (perhaps #32) close enough to a tuning fork that the fork hits it when vibrating. By putting this in the circuit as a switch, the same tone as the tuning fork can be heard in the speaker.

If the magnetic reed switch motors have been kept, return them now and put this loudspeaker in series with its electromagnet, to both feel and hear a click each time the switch closes. (Incidentally, collect the motors again and keep them for experiments in induction later on.)

Finally, once the association of sound with vibrations has been established, use one or two transistor radios to listen to a local radio station through these loudspeakers (really earphones). Use the earphone cord, with the earphone snipped off. Feel the vibrations on the bottom of the cup while listening.

Incidentally, a particularly amusing demonstration of how a loudspeaker operates can be performed nicely with the earphone of a transistor radio. (Spares are available from Olson, (PH-112), 2 for 49¢). If the plastic stub designed to fit in the ear is carefully removed, the iron diaphragm is exposed, and removing it exposes the tiny central coil as well as the ring-magnet which holds the diaphragm in place. This magnet will hold the earphone body to any piece of sheet iron such as a metal box or tin can, and if connected to the radio, the metal will vibrate and radiate sound just like the original diaphragm. Even a steel pin or a paper clip laid across the coil will produce enough sound to hear.

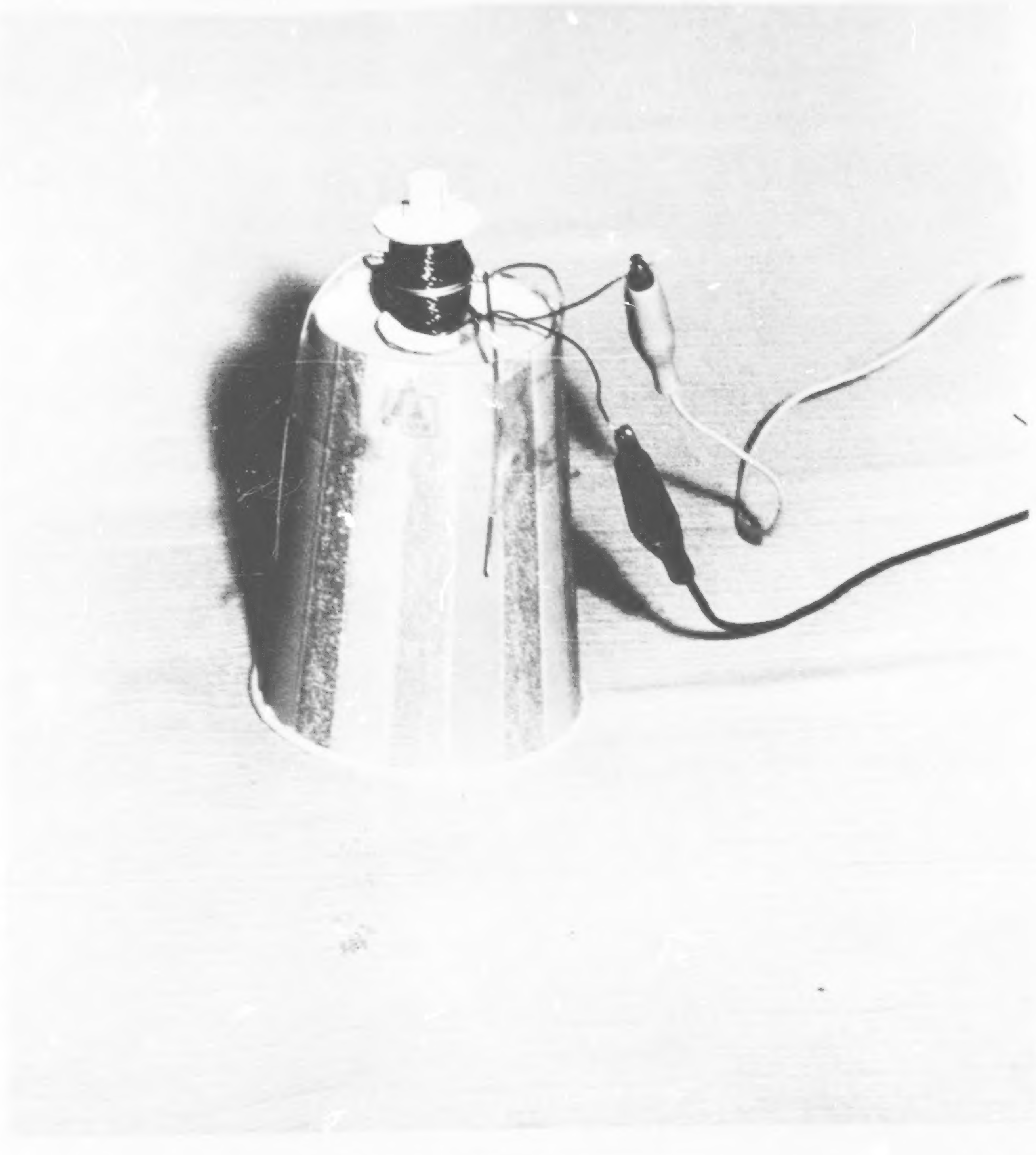


Fig. 11 Paper-Cup Loudspeaker

To make the association with commercial speakers, give each boy a small commercial speaker to repeat some of the above experiments. (As leads he will need 15" of #24, 2-conductor miniature speaker cable. Strain-relief can be provided by splitting the two halves of the cable apart for about 3" and wrapping them around the speaker yoke before soldering to the speaker lugs.) Turning it face-up and sprinkling a bit of salt or sawdust on it to "dance" makes the vibrations very visible. It is also very effective to put the speaker in parallel with a slot-car motor to hear the commutator hum,or change its pitch by braking the motor . Carefully dissect one speaker so the boys can see that the permanent magnet is fixed in a commercial speaker, and it is the coil, attached to the cone, which vibrates.

3. Other General Experiments. Using, for instance, the Stansi apparatus, together with a borrowed vacuum pump, suspend an electric bell in a jar (6V battery works best) and pump out the air, to hear the sound fade.

A useful introduction to a light-sensitive resistor can also be made in the context of sound. The better commercial cadmium sulphide "photocells" have a resistance which varies from about 500KΩ in complete darkness to about 50Ω when held directly adjacent to a 100 watt light bulb. Consequently even if put in series with a 9-V transistor - radio battery, it is difficult to get 100 mA through it. The variation can be seen nicely by putting a low-current (60mA) bulb, GE #48, in series with it (perhaps mounted inside a mailing tube or tin can for easier visibility) and turning the CdS cell towards and away from the sunlight.

Loudspeakers will also respond to very small currents such as these. It is not difficult to mount a slot - car motor on a board with a 4" cardboard disc affixed to its gear and perforated by 4 or more equally - spaced slots to make a light - chopper when it rotates. If a CdS cell is illuminated by one of the D-cell flashlights previously built, with the beam chopped by this rotating wheel, the chopped current driven through the photoresistor by even a D-cell will produce a sound like a motorboat in one of the commercial speakers. If the audio stage of a transistor radio circuit is used to amplify this current (see 12th Day, below), the sound can be heard by the entire class at once.

4. Carbon - Rod microphone. The diaphragm is the top of a thin plastic 1 - pint food container, such as is often used by delicatessan shops for potatoe salad, etc. (A pasteboard ice cream container might work, but is very stiff.) Two 1/2" x 1" strips are cut from 1-mil thick shim brass, with one side of each in a slight concave-crescent shape. 4" of 2-conductor phono pickup lead are attached, one lead soldered to an end of each brass strip. The strips are then glued by one side, concave-edge up, to the inside of the top of the plastic container, parallel to each other and about 1/2" apart; the phono lead is run through a hole near the edge of the top and tied to provide a strain-relief.

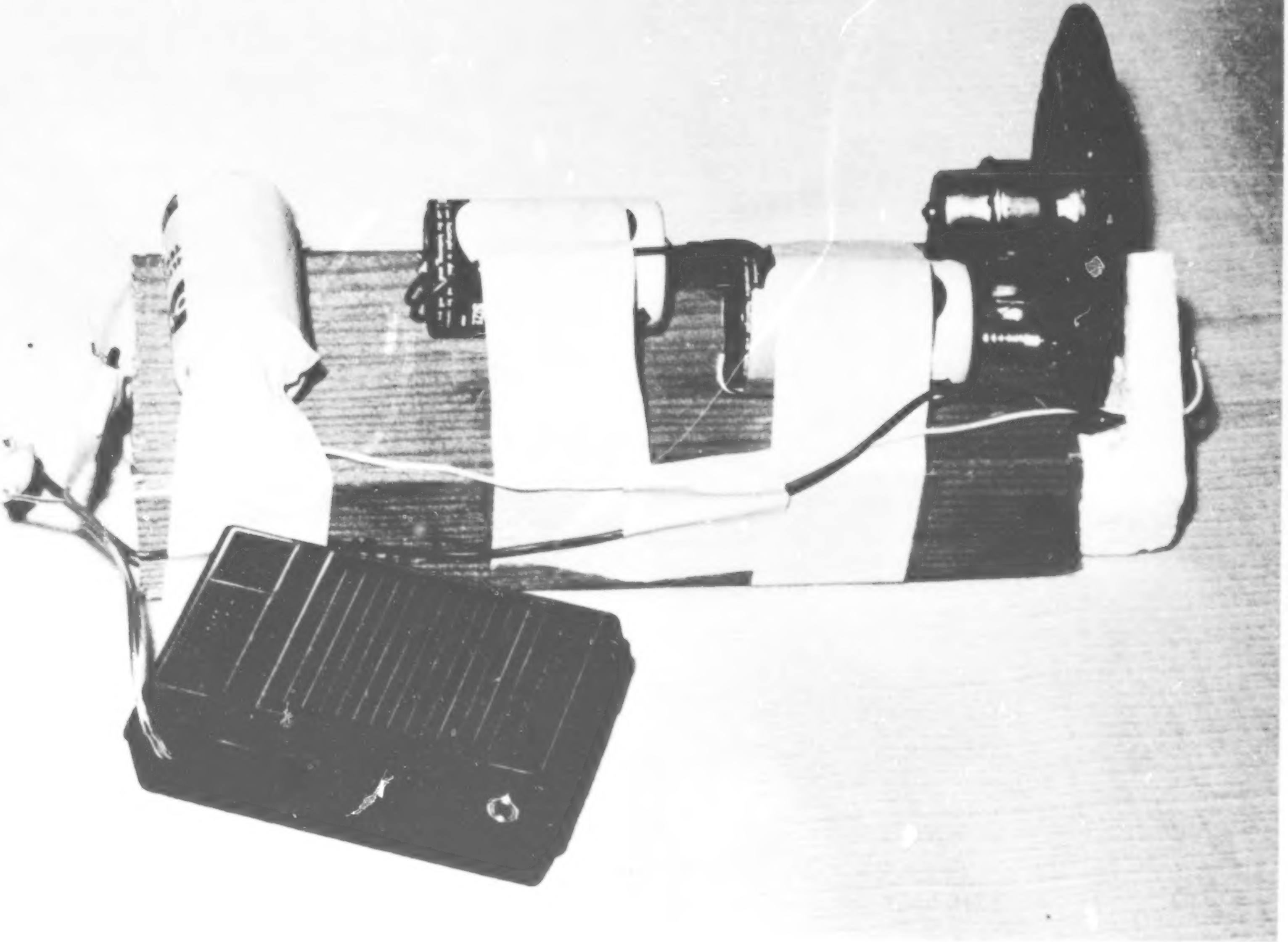


Fig. 12 Light-Chopper, with Photocell and Transistor Radio Amplifier

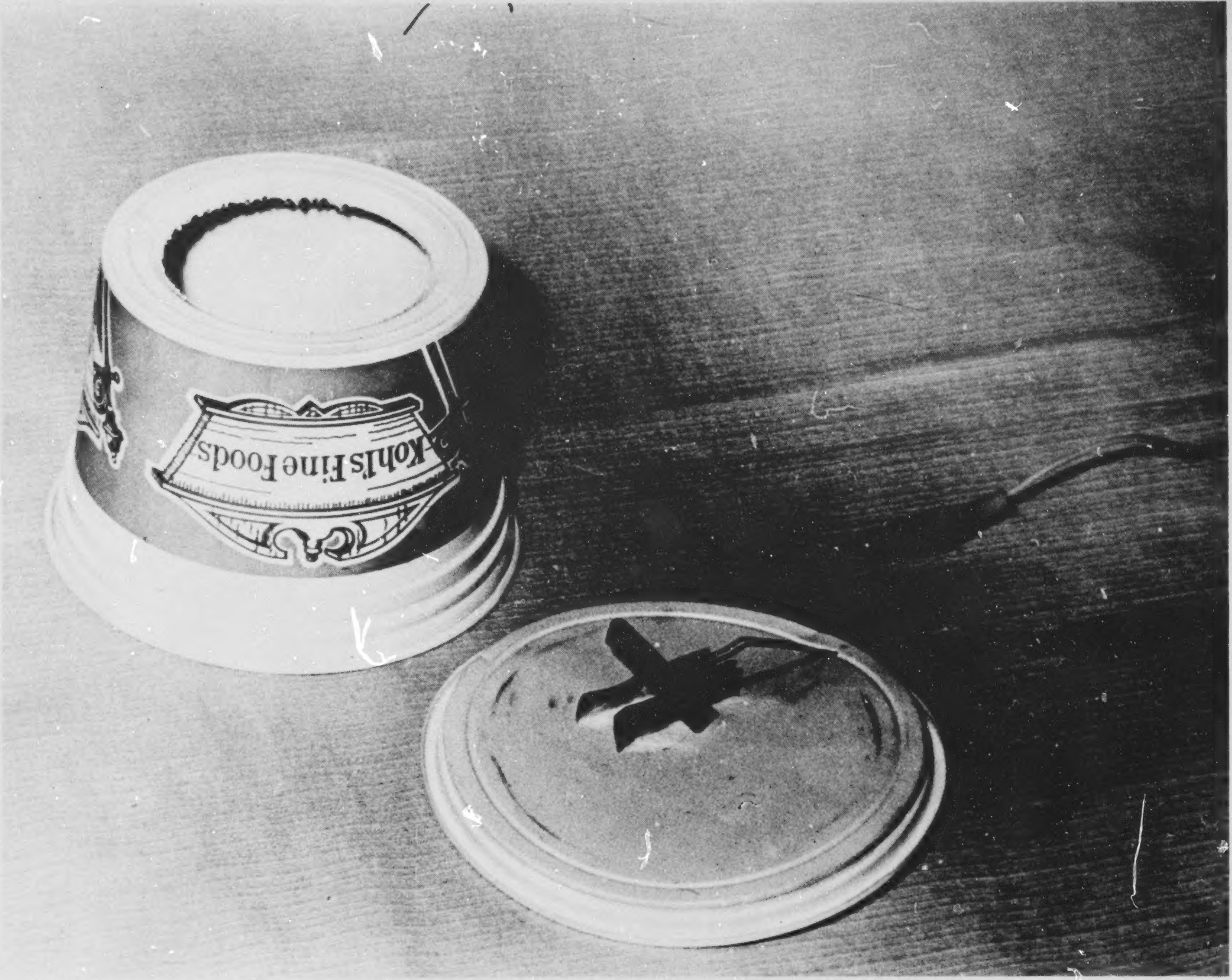
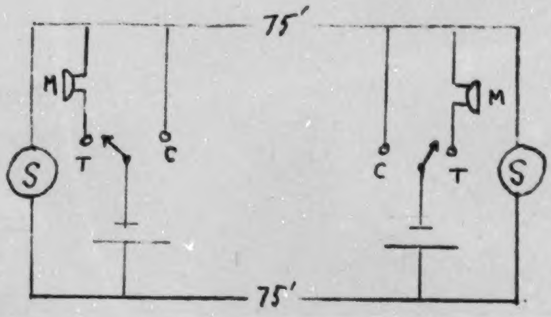

Kohl's Fine Foods

Fig. 13 Carbon-Rod Microphone

A 1" length of 3/16" diameter carbon rod (sandpapered a bit) laid across the brass strips (the crescent shape prevents it from rolling off) completes the circuit between them. If the phono leads are connected to 75' or so of 2-conductor cable, whose other end is connected to a commercial loudspeaker (unfortunately the paper-cup ones are not sensitive enough) with just a single D-cell in series, the device makes a very acceptable 1-way telephone. Any vibration of the plastic container lid caused by talking near it causes the carbon rod to bounce and interrupt the current through the speaker at the same frequency; the result is quite intelligible speech. Actually, the sound coming out the speaker is loud enough to hear only if the body of the plastic container is replaced, upside down, on the lid to act as a resonant cavity. The bottom of the container must be cut out first, which can be done conveniently with a hole-saw.

5. Two-Way Telephones. Although the above telephone works, it is fragile and unstable. A good, durable 2-way phone is likely to be one of the most exciting and practical of all the projects the boys will build, and the one described here does the job well. The speakers are left in the circuit at all times. Pressing your "talk" (T) button sends a current through your microphone (and incidentally through both speakers) so that you can talk. The current is quite small because the resistance of most carbon-



grain microphones is fairly large 100Ω or so); pressing the "call" (C) button instead will bypass the microphone and emit a loud click from the speakers, to let the other end know you wish to talk. Both switches are spring-loaded to keep them in the normally-open position. In fact, both can be made of a single 3" piece of band-saw blade, which can be swung and depressed to touch either the T or C contact, both of which are sheet-metal screws. A 4" x 6" piece of 1/4" hardboard makes a convenient base, with two pieces of slat material screwed flat to the back as "legs" to allow space for the wiring there. A single D-cell at each end provides adequate power, and all components except the speaker are fastened on the board with screws or soft, heavy copper or aluminum wire. (Round-style carbon grain mikes can be mounted in styrofoam and wired to the board.) The speaker (earpiece) is on 12" or so of speaker cable, and is the same one used above. With a little ingenuity, a "headband" can be improvised from a coat hanger, which will hold the speaker to the boy's ear and leave both hands free.

It is advisable for each boy to build both ends of a phone system, so that he can use it with friends or relatives not in the course.

If time is allowed for experimenting with the various devices as they are built, and for thoroughly trying out all three kinds of telephones (indoors and out), there are two full days of work here.

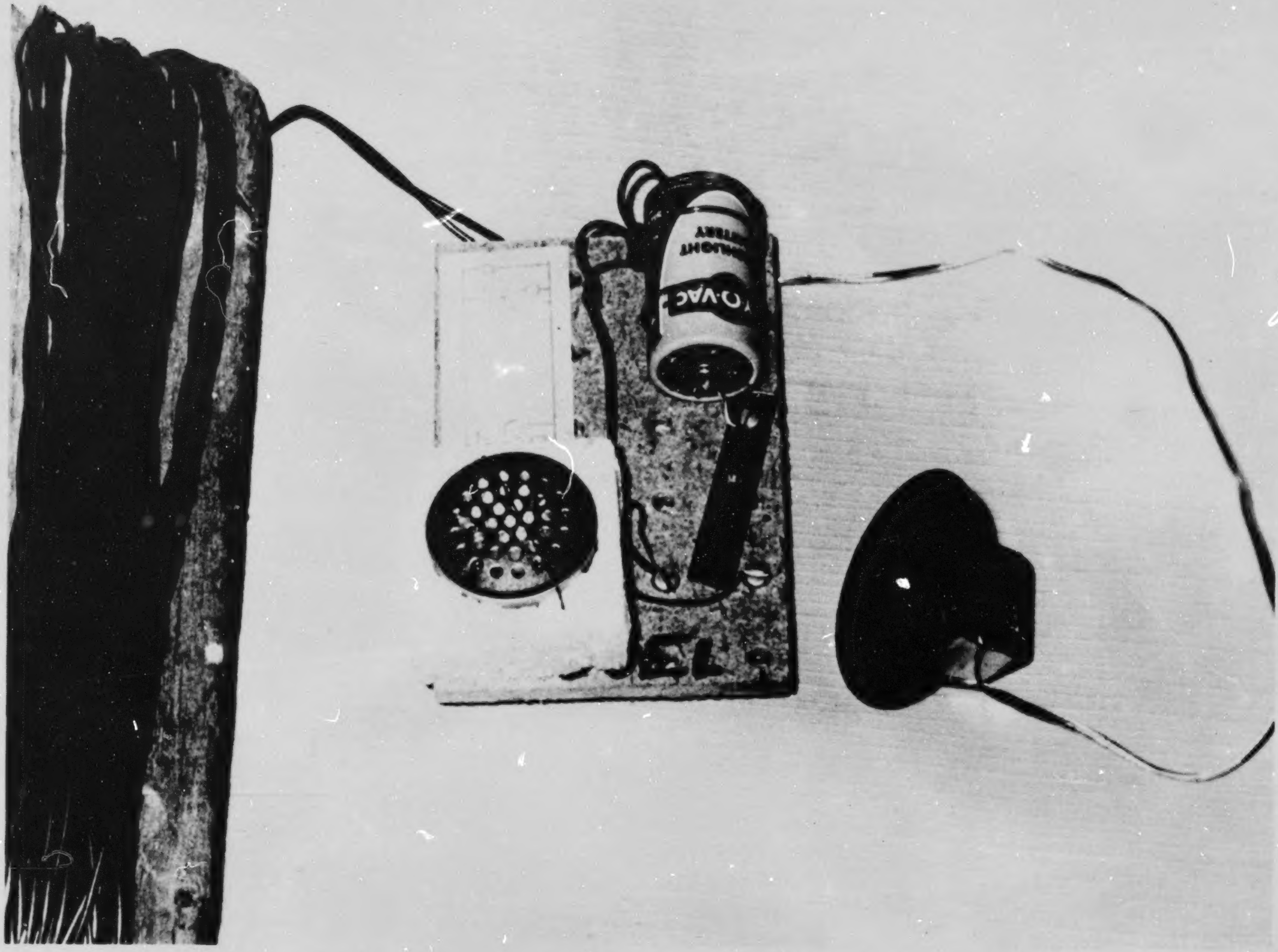


Fig. 14 Two-Way Telephone (one end, with wire)

Incidentally, although the boys shouldn't be told yet, since they won't understand it, this telephone system will also work entirely adequately without switching in the battery parts of the circuit at all, i.e., just two loudspeakers in series at opposite ends of the line. Since they are permanent - magnet speakers, vibration of the coil in the field of the magnet will induce a current which the opposite speaker will pick up; in other words, each speaker can be used as both speaker and microphone, without any battery at all. Since the batteries of the present arrangement will eventually run down, the boys should be told of this alternate mode of operation after they have learned about induction. Putting two speakers in parallel at each end, to use as speaker and microphone, makes it more convenient to use.

12th Day. Transistor Radios. Induction: Generators.

Number	Supplies per boy	Total Cost	Supplier
1	Inexpensive transistor radio, with 9V battery, earphone and earphone jack.	About 4.00	
1	Cadmium sulphide photocell (TR-91)	.30	OLS
1	9V transistor radio battery (BA-89)	.20	OLS
1	2 1/2" speaker, 8-10 ohms, square yoke (S-641)	.44	OLS
15"	2-conductor miniature speaker cable		
1 (per 3 boys)	0-200 mA inexpensive DC milliammeter (2330B, EMICO)	3.35	SAT
40'	#26 enamelled magnet wire		
1	5/16" diam. heavy plastic straw		
1	2" x 1/4" diam. alnico bar magnet	.70	AMP
1	3-V slot car motor, Russkit 34 (SL-59)	.25	OLS
1	GE 113 flashlight bulb (25F140)	.13	NEW

General Equipment: Magnetron magnet (borrowed from high school or university physics lab, or #60,461 from ESC for $12.50); magneto generator with light bulb (Stansi #43585, $13.00). Locating very cheap transistor radios can be something of a problem. A local discount or dimestore is probably the best source. If not, try writing to the Radio Section of E.J. Korvette, 8700 S. Cicero Ave., Oak Lawn, Ill. 60454, Tel. (312) 635-5110. They usually have an 8-transistor radio, with earphone and battery, for about $4.00. For detecting small induced voltages, try to borrow a few sensitive galvanometers or *moving* - *coil* milliammeters (0-5 mA is good) from a local high school. Several spare 9-V batteries (Olson, BA-89, 20¢ each) should be on hand.

1. *Transistor radio used as Audio Amplifier*. An amplifier is needed to make several of the induction experiments feasible, and a cheap and usable one is available in the audio stage of an inexpensive transistor radio. Using it serves the additional purpose of demonstrating that commercially - available circuits are not "sacred", but can be modified to serve alternate purposes.

Each boy should be given a transistor radio (the cheapest one available, provided it has an earphone and earphone jack). This will occasion boundless excitement which will, however, be tempered by the announcement that the gift is contingent upon their ability to solder extra leads into the circuit to bypass the detector and give an alternate input for the audio-stage amplifier. Again a clip-lead (preferably the larger miniature variety, for strength) cut in half works nicely. If an extra hole is drilled through the case before handing out the radio, the two halves of the lead can be knotted together inside the case, and the knot used for strain-relief at the hole. Only about 1/8" of the cut ends should be stripped and tinned, and soldered in at the beginning af the audio stage. These points are usually the two outside or end terminals of the volume-control potentiometer, but if this fails to work, the correct points should be located well in advance of the project, with the assistance of a radio repairman if necessary. The radio can still be used conventionally; if the audio stage alone is desired, simply tune off the local stations. If connected as above, the volume control will work for the clip-lead inputs as well as for the usual detector, which is very convenient. Considerable care must be taken in soldering these leads in to prevent damaging the circuit, and it can only be done with a fine-tipped iron. (It is a good idea to have a few extra radios in case of disasters.) The importance of having an earphone jack is that by using it, with the earphone snipped off (leave a few inches of lead on the earphone, so it can be reconnected if desired), the earphone leads can be used as output from the amplifier, if you don't wish to use the speaker of the radio as output device.

A cadmium-sulphide photoresistor is a nice thing to try as a first input (using the normal radio speaker as audio output). Put the CdS cell, a 9-V transistor radio battery, and the new input terminals to the radio in series, so that any current changes through the CdS cell will be amplified by the radio amplifier. The simplest thing to do is point the CdS cell towards a window, and wave your outstretched fingers in front of it, as a multiple-shutter or light-chopper, giving a motorboat-like output on the speaker as the shadows of the fingers cross the photocell. It is important that the shadows have sharp edges; it might be interesting to let the boys experiment with small and large light sources to see how "softening" the shadows affects the sounds. Merely walking closer to or farther from a window may produce the desired effect. (If the sun isn't shining brightly, the shadows will never be sharp enough. Use an electric light bulb (small, not fluorescent). Perhaps they can devise other types of rotating-wheel, etc., light choppers.

Secondly, the CdS cell will very nicely pick up 60-cycle hum, but unfortunately most radio amplifiers are specially constructed to reject it, so that normally it can't be heard from an incandescent light bulb. However, a fluorescent bulb turns off and on much more sharply each cycle and so has plenty of overtones, which come through the amplifier very nicely. It is particularly impressive to pick it up from reflected light, especially in the presence of daylight, which is indistinguishable to the eye but of course produces no hum on the radio. The CdS cells and batteries, incidentally, must be kept in the tool boxes and not sent home, for they will be needed later. An extra speaker is going to be needed directly below, but before putting it to that use, have the boys connect it in the above circuit in place of the radio, to show how substantially the amplifier increases the sound output. Incidentally, with just the speaker as detector, 60-cycle hum from incandescent light bulbs can be heard.

With this as background, the boys can have enormous fun by using a loudspeaker - again with 15" or so of twin-lead - as a dynamic microphone. Even though they don't yet understand its operation, they can easily clip it in as input on their radio amplifiers, to make a "public address" system out of them. And they will soon enough find out that bringing the microphone close to the radio speaker will produce a fine feedback squeal! If they have not yet taken home their telephones from yesterday, give them an opportunity to discover that the amplifier can also be used very nicely in place of the speaker-earphone they previously installed. It may suffice simply to clip it in parallel with that speaker. If not, either put it in series with the speaker, or disconnect the speaker from the circuit altogether (unsoldering one lead is sufficient). However much the boys may be tempted to take the radio home with the telephone, make it clear that the radios (and the extra speaker) must stay behind for the time being, to be used in other projects.

In fact, if the final week or so of activities are to be restricted to a smaller number of boys, this is a very appropriate time to make the change. It means that everyone who has lasted this long is rewarded by a radio, and the fact that he can take the radio home immediately provides a great incentive to him to call it a day at this point. This will probably be encouraged by the fact that the rest of the day's activities will be more "experimental" and involved with the fundamental phenomenon of induction than with practical gadgets. Finally, since the radios are more expensive than other things the boys have been given, and since there is such a great temptation to take them home at once, it would be very wise to label them with the boy's names and collect them each night, for safe-keeping, before the boys leave. This has the further advantage of guaranteeing that those boys who have decided to continue on for the last week of the program will stick by their decision. Once they learn of your intention to keep their radios, however, you may have some fast talking to do to convince any of them to remain for the last week!

2. Induction; generators. For detecting low-frequency induced voltages, a high school galvanometer or a sensitive moving-coil DC milliammeter is excellent. The milliammeter should not have an internal shunt, and will produce the maximum deflection if its resistance matches that of the straw-wound coil, which is 1 or 2 ohms. For instance, a Simpson or Triplet 0-5 mA DC meter is excellent; new it costs about $20, but can often be obtained from military surplus outlets for much less. As a less desirable alternative, an inexpensive fixed-coil milliammeter of 1 or 2 ohms resistance, such as the Emico #2330B,

0-200 mA DC meter, available from Satterfield for $3.00, will do a passable job. The Olson multimeter, on the 2-5 mA range, will also work, but is quite highly damped. For higher-frequency induced voltages, a loudspeaker is a very sensitive detector; the ultimate in sensitivity is the radio-amplifier, again with audio output.

If a magnetron or other strong magnet is available, an excellent introduction to induction is to make a single large loop of 3' of hookup wire, with its ends attached to the 5 mA ammeter. Moving a section of it rapidly between the poles of the magnet will produce an easily-seen deflection on the meter. Letting the boys see who can get the largest deflection makes a good game. Then set them the problem of how to get a larger current from the same magnet, and let them work out the fact that making more smaller loops (in the same direction) out of the same length of wire, so that several wires move through the magnet gap together, will double, triple, etc. the induced current.

Second, remind the boys of the experiment in which the swinging aluminum plate was stopped when it passed between the poles of a magnetron magnet. With small bolts, attach a pair of leads to the sides (not ends) of the plate, and use a milliammeter or microammeter to show that a current is induced by the motion of the plate through the magnet, which flows crosswise to the direction of travel. It is exactly as though the plate were a series of generator wires (transverse to the direction of travel), in which currents are being induced, and technically it is known as the Hall Effect. It is the interaction of the magnetic field produced by these induced currents, with the field of the permanent magnet, which gives the "drag" effect.

Next, wind coils (as short and compact as possible) of 40' of #26 magnet wire at one end of 5/16" diam. plastic straws leaving the entire straw intact, and induce a current in them by moving a 2" x 1/4" diam. alnico bar magnet through the coil. This is readily detected with the milliammeter. However, if the magnet is dropped straight through the straw (to give it some speed), especially if the coil-end of the straw is rested on a shoebox or other flexible object, so that the magnet bounces at the bottom of its run, a loudspeaker can be used as a detector; its motion can be both heard and felt. Just holding the magnet at an appropriate position within the coil and tapping it with the fingernail or scraping it with sandpaper or an emery board will also produce a very audible signal. All effects are louder still if the radio amplifier is used in place of the simple speaker.

An interesting alternative, which provides a louder click in the loudspeaker, is to put a nail or bolt inside the coil as an iron core, and tap it with the 2" bar magnet. This magnetizes the core abruptly, just as though a magnet were slid very rapidly into the coil, and so produces an induced pulse which clicks on the speaker. The fact

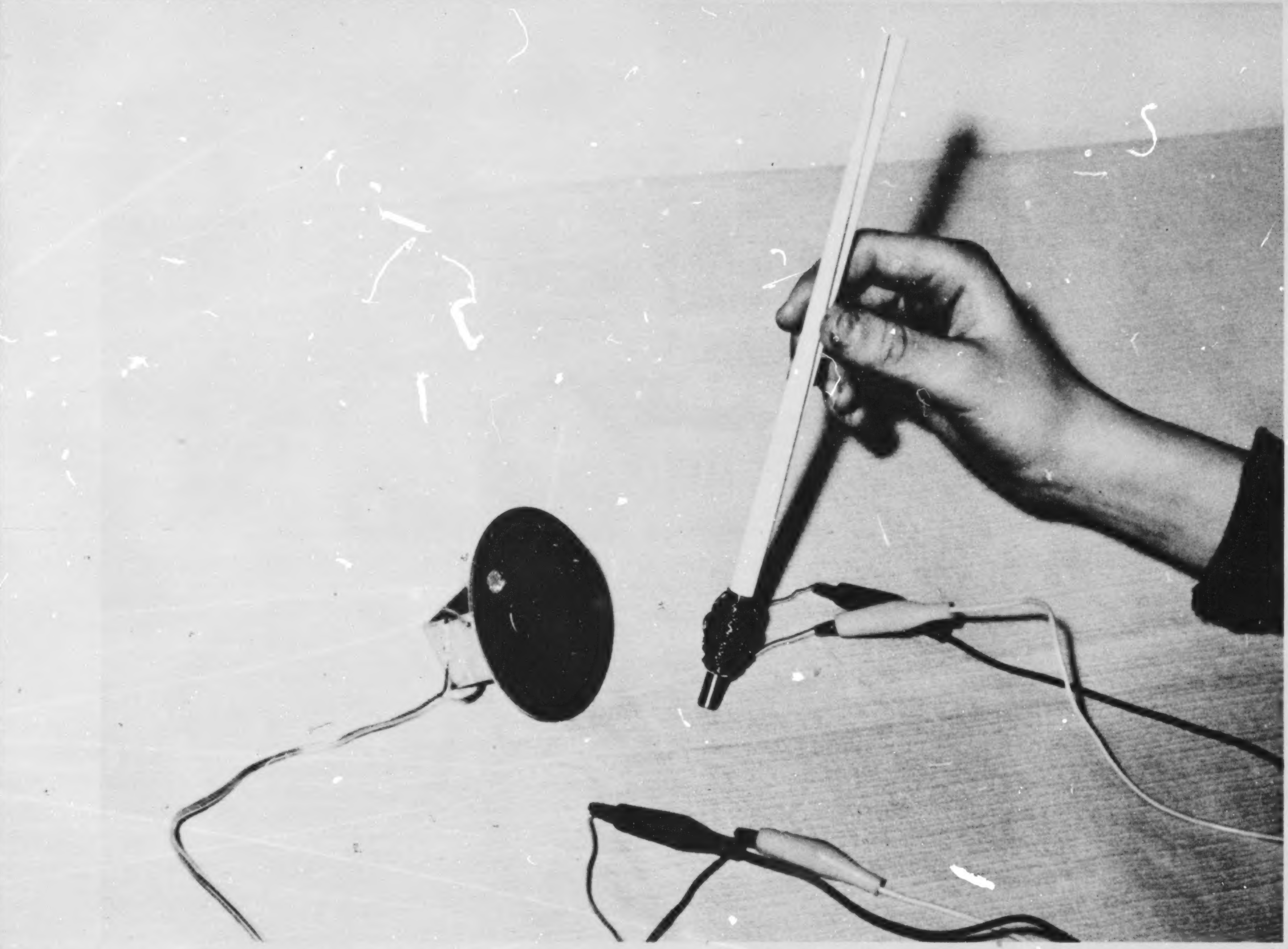


Fig. 15 Induction Coil on Plastic Straw, with Speaker as a Detector

that the poles of the magnet are located at its ends is made very evident by the fact that the click is heard if the nail is tapped with the end of the magnet, but is not heard if the tapping is done with the center of the magnet. Incidentally, with the core in place, deflections can be seen on the milliammeter when the magnet is simply moved near the coil, rather than inside it.

The connection with practical generators can be nicely established by handing out another Russkit slot-car motor to everyone (the Olson MO-169 motor, twice as expensive at 4/$2, is also twice as good for this purpose) and pointing out that it also has a coil moving past a magnet because of the commutators switching on and off, the induced current is "chopped", and so will produce a motorboat effect if connected to a loudspeaker while the motor is turned or spun by hand. (The radio can of course be used in place of the loudspeaker, but may be confusing, since it has its own source of electricity inside.) Better yet, if a test-bulb socket is connected to the motor leads, with a GE 113 (single-penlight) bulb in place of the GE 14, spinning the motor by hand will induce enough current to flash the bulb brightly. Of course, if one boy uses his motor (powered by two D-cells) to drive another as a generator, it can be used to light a bulb steadily. If you want to be really fancy, shine this bulb at a CdS cell in series with a radio-amplifier, to verify that the light is really not steady but is being modulated by the same ripple which can be heard by connecting the generator directly to a loudspeaker. It is a perfectly good analogue of the 60-cycle hum heard when the CdS cell is aimed at a fluorescent lamp. Again, this is the sort of thing which is likely to be most fun if the boys try to guess in advance what to expect when the system is hooked up.

If the Stansi (or other) magneto has been purchased, this is the time to allow the boys to play with it. Some caution is in order, for it will give substantial shocks if turned fast. While a boy is turning the crank with the circuit open, screw in the bulb (or short across it with a screwdriver) to let him see that the crank is much harder to turn when the generator is actually doing work, like lighting a bulb. It is exactly the same force which stops an aluminum plate swinging through a magnetic field.

None of the things (including motors) used or constructed today should go home; they'll all be needed later.

13th Day. Induction: Transformers.

Number	Supplies per boy	Total Cost	Supplier
2	D-cells	.16	OLS
1	3" spike		
1	2" x 1/4" hexagonal-head machine bolt, nut	.10	
40'	#26 enamelled magnet wire		
1	Inexpensive audio output transformer (18A888)	.49	BA
1	Neon glow lamp, NE 2A (12A4129)	.08	BA

General supplies: Four 2" diam. magnifying glasses, (40,024) from Edmund for 50¢ apiece.

1. Simple Transformer. Wind about 12" of a 24" length of #26 enamelled magnet wire around a 3" nail (leaving two 6" leads) as a primary. If it is connected to two D-cells in series and moved rapidly in and out of the straw coil wound yesterday, it will induce enough current in this coil to produce a small deflection on the milliammeter. The point is simply to emphasize that a current can be induced by a moving electromagnet as well as by a moving permanent magnet - but do it only for a few seconds, since the 24" wire is a dead short across the batteries. This should make it more plausible that turning the primary - circuit current off and on is like moving the primary electromagnet in and out of the secondary coil, and so induces a current in the secondary coil which can be heard as a click on the loudspeaker detector, but only when the current is changing. Be sure to emphasize that the primary and secondary coils are insulated from each other, and that nothing is heard while the primary current is running steadily. Scratching the primary lead along a file or sawblade to interrupt the current produces nice static in the loudspeaker or radio attached to the secondary; putting a motor in series with the primary will induce a buzz in the secondary if the motor is spun by hand (without even using a battery in the primary; the motor generates its own current).

By far the most impressive effect, though, is obtained with the output from a transistor radio. Snip the earphone off its cord and strip the remaining leads for 1/4" or so. To show that they indeed produce a current when a station is tuned in, it might be wise to have them connect these output leads to their spare speaker for a moment. Then, connect the output lead instead to the primary coil of the transformer (without any battery) and move the speaker to the secondary. Because the primary current is constantly changing, it induces a corresponding audio current in the secondary, which drives the speaker and emits a perfectly clear reproduction of the sound. It is especially nice because the sound intensity decreases as the nail is pulled out of the secondary coil; usually a faint sound can be heard with the primary and secondary simply side-by-side.

Although it is cheating a bit, it is perfectly reasonable to think of the primary coil as a transmitter, broadcasting electromagnetic (not sound!) waves, which are received by the secondary. Let them verify that the receiver becomes more sensitive if a 1/4" bolt is inserted in it, and use this as a motivation for winding another 40' coil directly on the bolt. Now consider the bolt as the secondary, and use the previous straw-wound coil as a primary, to "broadcast" from the output of the radio to the bolt with speaker attached. Simply starting and stopping a current (D-cell) through this new primary produces a pulse which can be picked up at some distance away by the bolt - secondary, especially if the radio amplifier is used in place of the simple speaker. From here on, they can go about exploring the room for electromagnetic waves. If the reed - switch motors are still available, they make a fine buzz (close observation with the pickup coil will show that it is the spark across the terminals of the reed switch which is doing the broadcasting), as does an operating slot-car motor (the sparking commutators broadcast). A neon-bulb flasher produces clicks, and a discharging Van de Graaf generator will make big ones. 60-cycle hum from electric motors (clocks, refrigerators, pumps, etc.), or from transformers (for doorbells, etc.) can be picked up nicely this way, using either a speaker or the radio amplifier on the pickup coil. Most 110-V lines, switches, wall-sockets, etc., however, are well enough shielded (if built within the last 15 years) that they do not radiate.

2. Commercial Transformers. A cheap audio output transformer has a large primary/secondary ratio, large enough that switching the secondary current on and off (1 D-cell) will give a tremendous shock to anyone holding the primary leads. For more fun, have several boys hold hands in a circle, with the end ones holding the primary leads of the transformer. It will easily fire a neon lamp (in fact, several in series) connected across the primary; scratching a secondary lead along a file or saw-blade to interrupt the current will make the lamp glow continuously - but do not touch the primary leads in this case, for the shock is too much for comfort. If a slot-car motor is connected directly to the secondary leads (no battery) and spun by hand, it will momentarily light up a neon lamp on the primary; the changing voltage generated by the motor is stepped up to more than 90 V by the transformer.

Even better, if the secondary resistance is low enough (a few ohms), a slot-car motor in series with it (this requires 2 D-cells) will continuously interrupt the current and produce a continuous glow in the neon lamp on the primary. The same can be accomplished by using a buzzer in place of the motor.

Before using these commercial transformers, dissect one so the boys can see how it is made.

3. Sound Transmission on a Light Beam. Although it has nothing to do with induction, this is an appropriate time for the boys to play with a very interesting effect. If a GE 113 (one-penlight) bulb is put in series with a single D-cell and the earphone (output) leads from the radio, an audio A.C. flicker (amplitude modulation) will be superimposed on the DC light produced by the battery current. A visible flicker can even be seen, due to current surges accompanying louder and softer sounds, which is a nice indication of how the current is carrying the audio information. Far better, though, is the fact that if a CdS cell is put in series with a 9V battery and the extra loudspeaker, then the modulated light can be "read" by the photocell, and the radio sounds come clearly out of the speaker - carried on a light wave rather than on a radio-frequency wave. Its loudness depends, of course, on how much of the focussed light beam falls on the photocell. This is an ideal time to introduce the idea of a lens, as a light-collecting and focussing device. By using the 2" Edmund magnifying glass to focus the flickering light

on the CdS cell, the "broadcasting distance" can be increased greatly.

14th Day. Optics and Shoebox Cars.

Optics

Number	Supplies per boy	Total Cost	Supplier
1	Chipped-lens kit (lens kit #2)	1.50	ESC
1	Mailing tube, about 1.5" I.D., about 12" long (or sufficient black construction paper to roll a tube)		
1	Empty sewing spool, regular size		
1'	pre-gummed foam rubber strip, 1/2" wide		
1	1" dowel, about 4" long.		

General Supplies: Black construction paper, decorating materials for telescopes; microscope slides with center depression (Stansi 11565, $1.70 per doz), microscope cover slips (Stansi 11498, $.60 for 100).

4. Shoebox Car

Number	Supplies per boy	Total Cost	Supplier
1	Shoebox (adult size, not child size)		
1	3 V slotcar motor, Russkit 34 (SL-59) or (18B379,BA ,30)	.25	OLS
2	D-cells	.16	OLS
1	1 1/2" diam. styrofoam wheel, 1" thick		
1	1/2" diam. dowel axel, 6" long		
2	Large-size thread spools (about 1 1/2" long x 1 1/2" diam.)		
2	Spikes or dowels for spool - axels, with washers and plastic-straw sleeves.		
2	Rubber bands.		
1	1/8" hardboard or heavy cardboard, to fit bottom of shoebox.		

(Following items are suggested optional additions)

Number	Supplies per boy	Total Cost	Supplier
1	SPST Magnetic reed switch (18A1433)	.40	BA
1	"Button-magnet", 1/2" diam. (P-40,820)	.04	ESC
1	Flashlight bulb socket, screw base, soldering terminals, 90° mounting bracket (25F1318)	.23	NEW
1	Flashlight bulb, pre-focussed, GE 113, 1.2 V (25F140)	.11	NEW

General Supplies: Electrician's friction tape, masking tape, lacquers and water color paints. If not enough large-size spools are available, the non-driven one can be replaced by 2 smaller ones, end-to-end, but they should be mounted high enough to enable the car to travel over rough ground.

1. The $1.50 Edmund kit of chipped lenses is a very useful one, but it is wisest to hand out the lenses only as they are needed. First hand out the 33mm diameter, 223mm focal length lens just to play with. Although it can be used as a simple magnifier, the most important thing to do with it is to see that it will form an image of a light bulb or a distant window, on your hand or a sheet of paper. A bit of explanation of how lenses bend rays and form images may help, and it may be fun to make diaphragms with holes of various sizes, to see what effect they have on the image if held in front and behind the lens. The lens can also be used as a burning-glass if the sun is hot but not a very good one because of its small diameter.

2. 12.4-power telescope. Hand out the 7.5 mm diam., 18mm focal length lens as well and use the two of them to build a telescope. The 7.5mm one is a press-fit in a sewing spool, which makes a good eyepiece. For the body, a tube can be rolled from appropriately flexible cardboard if necessary, but a mailing tube about 1.5" inside diameter is better. There are many ways of fitting the spool and objective lens in; one rather

crude but simple one is to use strips of the pre-gummed foam rubber which is available in a long, 1/2" wide, strip, rolled, for use as padding or insulation around doors and windows. It can be stuck to the inside of the tube to provide rings which will hold the lenses in place. A "sandwich" of two pieces of styrofoam is equally good. Glue them together and to the inside of the tube with Elmer's glue, not airplane cement. The boys will be disappointed to find that the image is inverted, but it is quite clear.

This is another fine opportunity for the boys to use their artistic imagination, and it would be a good idea to provide them with paints, strips of colored tape, etc., to decorate their telescopes with. Or, as described for the light-signalling device on the 5th day, solid-copper hookup wire with colored insulation can be wound around the tube (if it is sturdy enough) to provide an interesting pattern.

3. 40-power microscope. (See the Edmund booklet for details) This need only be a few inches long. With care, it can nicely be built in a 4 1/2" length of 1" dowel, carefully drilled out for about 3 1/2" with a 1/2" bit from one end, for about 1/8" with a 3/16" bit (to fit the smaller lens) from the other, and finally the two joined with a 1/4" bit. This doesn't leave much for the boys to do, but again they can decorate it, and build a stand to put a microscope slide on if desired. It may be useful to have a hollowed-out slide (for drop of pond or lake water) and a couple of cover-glasses for each boy, and to spend some time looking at pond-water, sand, feathers, leaves, insects, etc.

4. Shoebox Cars, with Light Control.

These can be started in the afternoon, but will take all day tomorrow to finish. They are put in at this point because they make such an amusing toy when equipped with the light-operated switch, which requires a lens to focus light on the photocell if used indoors. They make an exciting project even without the photocell, so the light-switch elaboration should not be mentioned until all their other facets have been thoroughly explored.

Because most shoeboxes are not made of sufficiently stiff cardboard, the bottom should be doubled with a piece of corrugated cardboard or lightweight hardboard. Holes are cut in it for the spools, (cut H-shaped holes and bend the flaps back for extra strength) which run on spikes taped to the bottom of the box. Friction is reduced by using a plastic-straw sleeve between spool and axel, and washers at the ends of the spools. The non-driven spool can be set at an angle if desired, to cause the car to run in a circle.

The choice of motor for the car is determined largely by the funds available for the light-controlled switch. As explained below, if a \$2.00 relay can be afforded, any motor can be operated, and in this case a slot-car motor such as the Olson SL-59 (25¢) would probably provide the most power. If funds are limited and the 25¢ power transistor must be used in place of the relay, the BA motor 18B379 is better because it draws a smaller current (about 200 mA) and so is more readily regulated by a transistor.

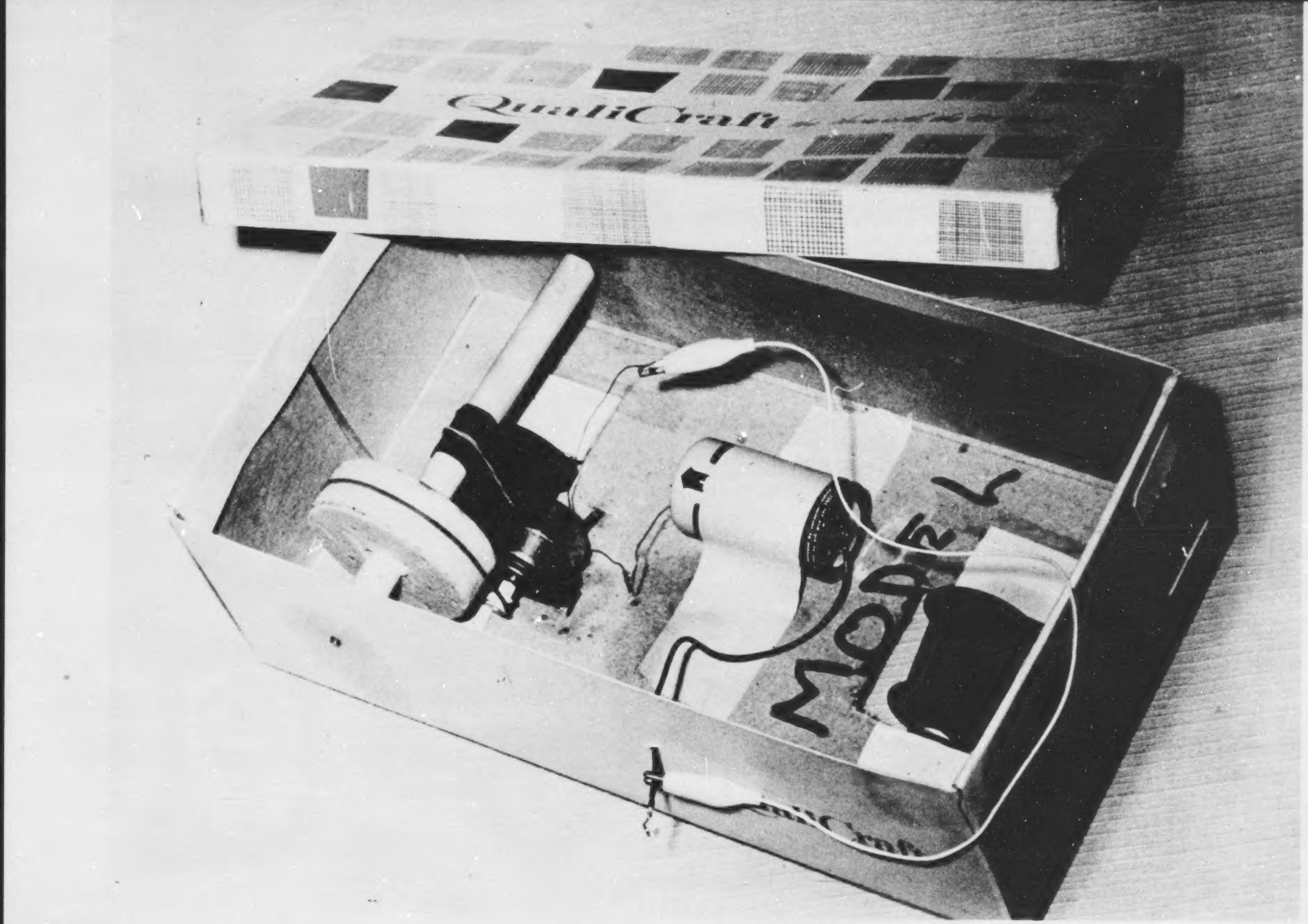

QualiCraft
MODEL L
QualiCraft

Fig. 16 Shoebox Car

A slot car motor can be fastened down with an aluminum strap as for the crane (this will require two 1/2" round-head bolts with nuts). The BA motor can be mounted by re-bending its mounting feet to insert them through slits in the bottom of the box; bend the projecting part flat on the other side. It drives the styrofoam wheel with a rubber band directly around its shaft; a 1/8" length of very small rubber tubing (1/16" I.D.) slipped over the end of the shaft will be necessary to prevent the rubber band from riding off if the BA motor is used. A stub of 1/4" dowel, drilled endwise with a 5/64" bit before sawing it off, will work even better. (In fact, if held in the chuck of a 1/4" power drill before being sawed off, a 1/8" rat-tail file (round) can be used to cut a groove around it which will turn it into a fairly acceptable pulley if desired.) A second rubber band from the 1/2" dowel shaft on which this wheel is fastened turns a spool below it. The dowel shaft turns on nails through the sides of the shoebox, and will need some electrician's tape to provide friction for its rubber band. The batteries are taped to the bottom, and a wire is stuck through the side, to which a clip lead fed out under the lid can be clipped, to make a serviceable on-off switch.

A car like this is just asking to be decorated, and it would be a very nice idea to provide the boys with appropriate spray-lacquer and water colors or other paints to use over them. Competitions for the best decoration could be held, as well as the obvious races.

If the boys feel like adding accessories to their cars, the possibilities are endless. A simple and useful one is a magnetic reed switch, taped to the underside of the box cover, and operated by a "button magnet" dropped above it. Another is a headlight. The prefocussed penlight style 113 bulb is probably best. It may be possible to use one of the motor batteries for it without unduly weakening the motor, but be careful not to use two, which will burn out the bulb.

15th Day. Light-Beam Remote Control Switch for Shoebox Car.

Number	Supplies per boy	Total Cost	Supplier
	1. Light Gun		
1	1" x 2" x 7" pine		
1	3/4" diam. pine half-round, 4 1/2" long		
1	4X magnifying glass, 2" diam. (40,024)	.50	ESC
1	D-cell	.08	OLS
2	GE 113 pre-focussed penlight bulbs, 1.3V (25F140)	.13	NEW
1	Flashlight bulb socket, screw base, 90° mounting bracket (25F1318)	.23	NEW
1	SPST open micro-switch, trigger-like action (SW-454)	.25	OLS
	2. Light-Controlled Switch.		
1	CdS photocell (20A22)	.99	BA
1	D-cell (to be added to the 2 from yesterday)	.08	OLS
2	9 V transistor radio batteries (BA-89)	.40	OLS
	Either		
1	SPDT relay, latching current about 6 mA (275-004)	1.95	RS
	Or		
1	PNP 10-W power transistor (276-527) (5/$1.00)	.25	RS
1	1/8" diam. x 1/4" round-head bolt, with nut	.05	
1	pocket mirror	.15	

General Supplies: Olson low-current motor MO-169 (4/$2.00), one BA photocell (20A22), 99¢, and two Olson 9V batteries, BA-89, $.40. Also about a square foot of opaque black construction paper, thin enough to roll into a tube, will be needed by each boy.

1. Light Gun.

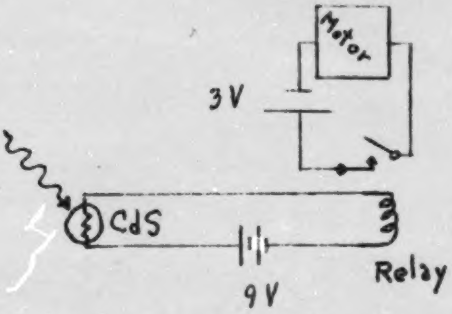
Whichever switching circuit is used, a focussed light beam is necessary to put enough light on the photocell to turn the motor on, and it is a good idea to make it before constructing the control circuit. The Edmunds magnifying-glass lens does a fine job of focussing, and works well with the familiar GE 113 pre-focussed penlight bulb, driven by a single D-cell. (Give the boys a chance to use the magnifier as a burning glass first.) It is essential that the two be held rigidly, a distance apart which can be adjusted to lie between 4" and 4 1/4". One method is to build a simple "light pistol" (the boys will call it a laser gun), whose "barrel" is a 7" piece of 1" x 2", with a 3/4" diam. half-round nailed along one end, extending downward to form the handle of the pistol. The D-cell can conveniently be taped to its forward side, as part of the handle. Any conveniently-shaped push-button switch could be taped to the front side of the battery as a trigger, but perhaps the nicest is an open microswitch which Olson sells 4/$1.00 (SW-454), whose lever is shaped exactly like a trigger. It can be nailed to the underside of the "barrel", with appropriately-drilled holes for the leads. A nail through the plastic cover (not through the hinge) of the magnifying glass will hold it firmly to the front end of the barrel. A 3" x 2" piece of styrofoam, cut into a U - shape, straddles the barrel like a horseman, and the bulb socket bracket is inserted into a knife-slit cut into it from above. Since the bulbs don't always shine exactly forward, it is wise to cut this slit after testing with the bulb, to be sure it points squarely at the lens. Sliding the styrofoam forward and backward focusses the beam at different distances. Since the bulbs don't last too long on a D-cell, have a spare for each boy.

2. Light-Controlled Switch.

The necessity for an elaborate switch is that the photocell has such a large resistance it will not pass sufficient current (with easily-obtained voltages) to drive most small motors. There is one motor which can be operated directly in series with the BA photocell, however, if the cell is held in direct sunlight and one or two 9V batteries used. It is the Olson MO-169, (4/$2.00) and should probably be set up as a demonstration. Unfortunately it is too weak to drive the car when used this way.

2A. Light-Controlled Relay Switch.

The simplest and most reliable switch is made by putting a CdS photocell in series with 9V and the coil of a very sensitive relay. The cheapest relay which will suffice is the Radio Shack 275-004 for $1.95.

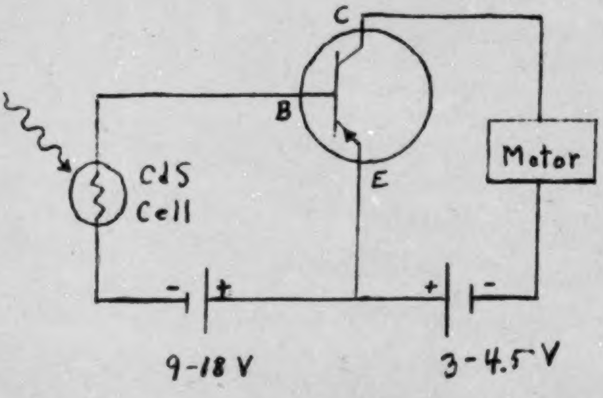


It will easily control 600 mA at 3V in the motor circuit. Its coil resistance is 500 ohms, and its minimum latching voltage is 3V, i.e., 6 mA through the coil. This coil in series with the photocell makes a voltage divider; with 9V across them both, 3V will appear across the coil when the photocell resistance is 1000 ohms. This occurs at a fairly modest light level (a small flashlight 10' away) for the BA photocell, and any light level in excess of this will pass enough current to hold the relay closed. Greater or lesser sensitivity is obtained by increasing or decreasing the coil battery voltage; it cannot successfully be decreased below 4.5 V.

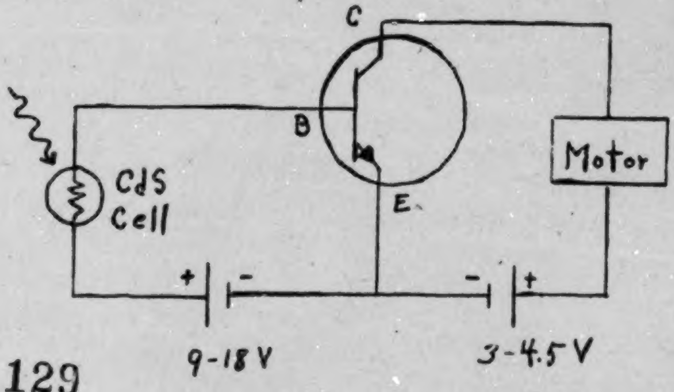
2B. Light-Controlled Transistor Switch.

This same job of controlling a motor current of several hundred mA can also be accomplished, and more cheaply, by means of a power transistor. Whether PNP or NPN transistors are used, the common-emitter configuration should be employed, with 2 or 3 D-cells in the emitter-collector(motor) circuit, and 1 or 2 9V transistor-radio batteries in the emitter-base circuit:

PNP Transistor



NPN Transistor



The two configurations are identical except for the reversal of the battery polarities. Transistors are easily ruined by applying the voltages backwards. To avoid mistakes, all boys should have the same type of transistor, and each should be marked (scratching is most permanent) NPN or PNP.

Power transistors are usually expensive, but the Radio Shack selection of "seconds" (267-527; five 10-W transistors for $1.00) provides very inexpensive ones quite suitable for this purpose. At least 4 out of every 5 should be good, but to be sure of a sufficient supply, 30 should be purchased for 20 boys. They may have a variety of shapes, but the case is always the "collector" terminal, and the "emitter" and "base" are marked E and B. It is a good idea to clip the circuit together first with clip leads to see that it works; for a permanent installation, one lead is connected to the collector (case) with a 1/8" diam. x 1/4" round-head bolt, which can also fasten it to the shoebox, (do not attempt to solder to the case), and the others are soldered to the E and B posts. A transistor is very easily damaged by soldering; do the soldering as quickly as possible (wrap the wire lead around the post first), and hold the post, near the case, with long-nosed pliers, which act as a heat sink.

The principle of the circuit is simply that the potential of the base relative to the emitter very sensitively controls the emitter - collector current. This E-B potential is in turn controlled by the amount of light hitting the photocell. The emitter-base junction has an effective resistance, which is in series with the photocell resistance and the base-circuit battery. When the photocell is dark, its resistance (perhaps 10^6 ohms) is much larger than that of the E-B junction; almost no IR drop occurs across this junction, so the base is practically at the same voltage as the emitter, and under this condition very little collector current will flow. If enough light falls on the photocell to drop its resistance (perhaps to 300 ohms) below that of the E-B junction, a substantial IR drop occurs across the junction, lowering the potential of the base relative to the emitter for a PNP transistor (or raising it for NPN), which greatly increases the collector current and turns on the motor.

Since the light from the "laser guns" is quite weak, the voltages and the shielding of the photocell must be adjusted so that the ambient or background light will not turn the circuit on by itself, but will still permit the laser - gun to do it. The first essential is that the photocell be well shielded from ambient light. Since this normally comes from above or from one side, a simple and effective procedure is to drill a 1/2" hole half=way through a 2" circle of 1" styrofoam and push the photocell into it, with the leads protruding through the back. Cover the back with black construction paper, and roll a 3" (or more) long tube of the same paper around the styrofoam circle, and tape it in place. The laser gun must be aimed into the tube opening. The tube should be so designed that in the desired ambient light, the "dark current" drain on the D-cells does not exceed about 100 mA, in order to conserve the batteries. (Use clip leads, etc. to disconnect both sets of batteries when the car is not in use.) The number of D-cells and 9V batteries is determined by the characteristics of the power transister, and will have to be tailored to each one separately since they vary quite a bit. At a minimum, one would like to be able to turn the motor on from 10 feet away with the light gun. In a room lighted artificially rather than by sunlight, many transistors will easily do this with one 9V battery in the base circuit and two D-cells in series in the collector circuit, but some will require two 9V batteries in series. If the car has a headlight, or if extra power is needed, use 3 D-cells in series in the collector circuit.

For indoor operation, the $1.00 BA photocell (20A22) is necessary, because of its low resistance and high sensitivity to small changes in light level. By the same token, however, it is really too sensitive to use outdoors, where it is nearly impossible to provide sufficient shielding against the ambient light. In this case it is better to use the Olson TR-91 higher-resistance photocell (2/59¢) which the boys received on the 12th day. It will be impossible to use the little light gun in the presence of sunlight background, but a small pocket mirror reflecting the sunshine onto the photocell down in its shielding tube will do the trick excellently. In this case one 9V battery on the base of the transistor will probably suffice. If even this is too much, remove it and connect the photocell lead (the one not connected to the base) between the two D-cells, thus tapping off 1.5 V from this source. Perhaps the most convenient arrangement for both indoor and outdoor operation would be to mount both photocells side-by-side in the same black-paper tube. Connect the high-resistance Olson cell for indoor operation. (It may also be necessary to add a longer shielding tube for outdoor operation.)

16th and 17th Days. Light-Beam Intercom.

1. Optics and Case.

Number	Supplies per boy	Total Cost	Supplier
2	4X, 2" diam. pocket magnifiers (40,024)	1.00	ESC
	Baseboard, mailing tubes and mounting hardware; or alternative mounts for lenses, transmitting bulb and receiving photo-transistor, including screw adjustments for alignment.		
1	GE 222 penlight bulb (2.2V, .25 A) (25F135)	.11	NEW
1	Flashlight bulb screw socket, soldering lugs (25F451)	.23	NEW
1	FPT-100 NPN photo-transistor (Semiconductor specialists)	1.25	
1	Carbon-grain microphone (M-135)	.50	OLS
1	SPST Push-button switch (18B770)	.20	BA
1	1" diam. bicycle-type reflector	.25	

2. Transmitter Amplifier

Number	Supplies per boy	Total Cost	Supplier
2	D-cells (BA-53)	.16	OLS
1	3.9 ohm resistor, 1/2W, 10% (13F050)	.10	NEW
1	220 ohm resistor, 1/2W, 10% (13F050)	.10	NEW
1	4.7K resistor, 1/2W, 10% (13F050)	.10	NEW
1	500 ohm trimmer pot (60F2233)	.39	NEW
1	1 Megohm pot, linear taper (9F235)	1.02	NEW
1	Pointer-knob for 1 Meg pot (35F1300)	.11	NEW
1	0.1 Mfd. capacitor ("orange drop"), 100V (18F2585)	.13	NEW
2	Signal-transistor sockets (12A5127)	.20	BA
1	2N3053 transistor, NPN (or 2N1711, $1.20)	.70	NEW
1	2N1307 transistor, PNP	.70	NEW
1	Pre-punched perf-board, 3 5/8" x 1 5/8" (276-1582)	.15	RS

3. Receiver Amplifier (optional)

Number	Supplies per boy	Total Cost	Supplier
2	D-cells (BA-53) (needed with or without amplifier)	.16	OLS
1	2 1/2" PM speaker, square yoke, 8-10 ohms (S-641)	.49	OLS
1	220K resistor, 1/2W, 10% (13F050)	.10	NEW
1	2.7 K resistor, 1/2W, 10% (13F050)	.10	NEW
1	0.1 Mfd capacitor (orange drop), 100V (18F2585)	.13	NEW
1	Signal-transistor socket (12A5127)	.20	BA
1	2N3053 transistor, NPN (or 2N1711)	.70	NEW
1	Pre-punched perf-board, 3 5/8" x 1 5/8" (276-1582)	.15	RS

Note that this price list allows only one transmitter and one receiver per boy; if he wishes to build two, everything is doubled. The transistor sockets are sold 10/99¢, the BA switch 5/99¢ and the perfboard is one 3 5/8" x 6 7/8" sheet for 59¢. A shaving mirror will be useful for aligning the devices.

This is the most advanced and difficult of all the projects, but also one of the most exciting. However, because of the difficulty encountered in its construction, and even more important in lining it up for use, it should only be attempted by boys who have developed a real talent and "feel" for handling technical equipment. Also, because it is strictly line-of-sight transmission, it is most successful for boys who live in "open" communities, with good visibility from house to house: it is better in a plains or prairie community than in a forest setting or in city apartment buildings. If the boys have the time and patience, it would again be best for each one to build two units, for he may not live within sight of anyone else following this program, and one station is useless by itself.

If each boy builds only one unit, two full days of work should be allowed for its completion. If each one builds two units, he'll need 3 days or more, and allowance must be made for this by eliminating one of the earlier days of the program. In either case, it is important that this project not be completed on the last day of the program, for the devices can only be set up successfully at night, and at least two evenings should be available for the instructors to visit all the boys at home and help them set up the intercoms for the first time.

The basic idea of the device is the one the boys already explored on the 13th day: if the current through a flashlight bulb is modulated by an audio-frequency signal, the light-intensity will "follow" the modulation. If this light is used to illuminate a photocell, the current through the cell is correspondingly modulated and, after amplification, can be used to drive a speaker and re-create the sound. It is exactly the principle of amplitude-modulation (AM) radio transmission, with a light wave (frequency 10^{15} cycles/sec.) used as a carrier wave in place of a radio wave (frequency 10^{6} cycles/sec).

In order to obtain any significant range, high-gain amplification is needed, which is obtained in part electronically and in part optically, by using transmitting and receiving lenses. By far the simplest amplifier to use on the receiver is that from the transistor radio. With it, the system described can easily be employed over a 100' distance. If the higher-gain receiver amplifier is built, this can be increased to 300' or more. Another approach worth exploring is greater optical amplification by the use of larger-diameter lenses. (Actually it is the f-number of the lens that counts, so increasing the diameter does not help if the focal length increases in the same ratio). Large lenses become very expensive, but remarkably large-diameter stamped-plastic Fresnel lenses have recently become available in many bookstores, which could profitably be used ahead of the regular receiving lens. Although their optics are of course very poor, they are quite adequate for focussing onto a 2" lens, and they gather a great deal of light. The American Scientific Co., 5700 Northwest Highway, Chicago, Illinois 60646, often has surplus Fresnel lenses available (#8891), as large as 11 1/2 x 12", for 79¢.

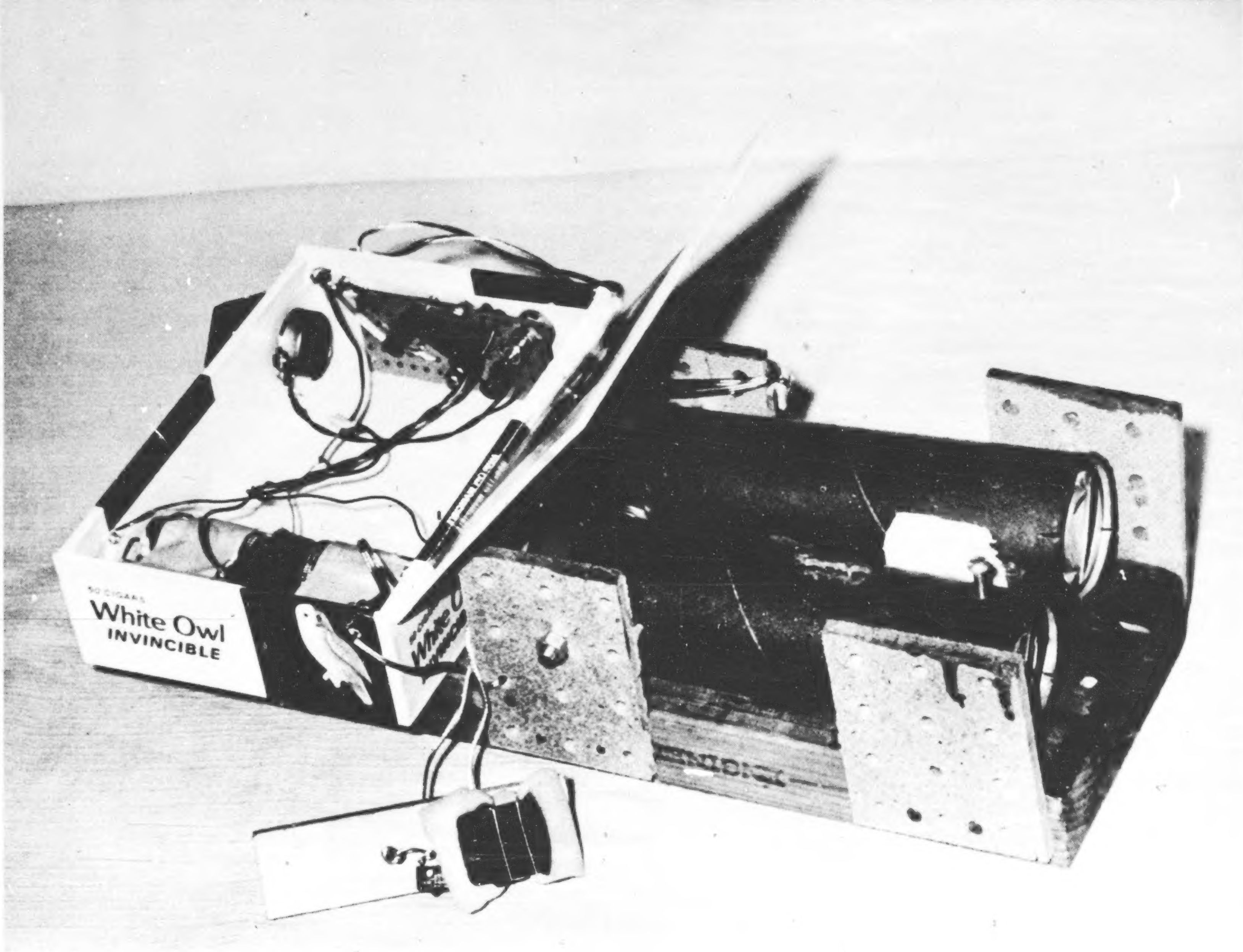

50 CIGARS
White Owl
INVINCIBLE

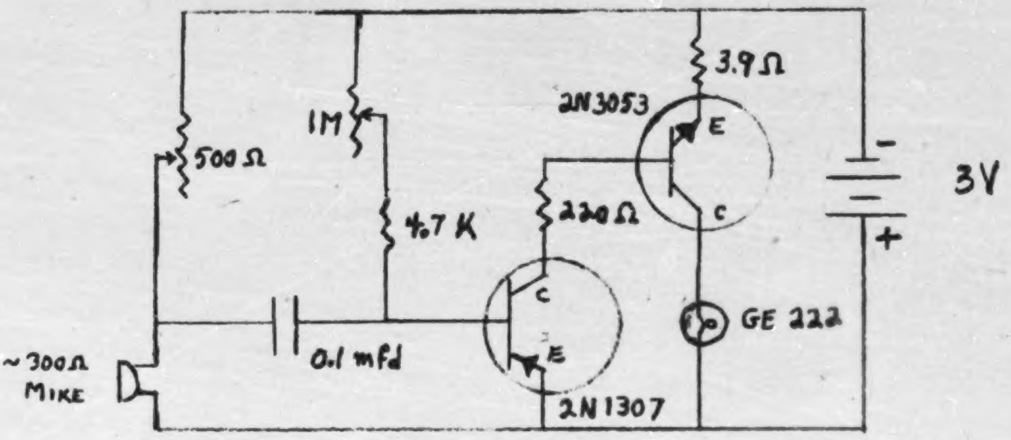
Fig. 17 Light-Beam Intercom

One possible design for the optics is indicated in the photo. The "hinge" protuberance on each Edmund magnifying glass lens was sawed off and filed down, and the lens carefully force-fitted into a 2" I.D. mailing tube. (These are not easy to find; a larger tube with a styrofoam lens mount would be simpler). The transmitting bulb is mounted in a block of styrofoam in one tube and the receiving photocell in a similar block in the other. Both styrofoam blocks must be movable for focussing, and the bulb mount must permit tipping, since the penlight bulbs are seldom focussed straight-ahead. Soldering the bulb socket to a heavy (#16) wire which can be bent is satisfactory. The major optical problem is aligning the two lenses so that the sending and receiving beams are very accurately parallel, so that when the outgoing beam from station A is aimed at the receiving lens of station B, the incoming beam from B will be focussed exactly on A's detector, and vice versa. This is a job the instructors will have to do themselves. It is best done at night, by reflecting a beam from a single station off a mirror at least 50' away and back onto the detector of the same station. (A pocket mirror will do, but a shaving-size mirror sends back more light.) The mailing tubes must be so mounted that one can be swung in a vertical plane and the other in a horizontal plane in order to make the two beams parallel. This requires very fine-adjustment control, and can only be done with threaded bolts which screw through appropriately-sized holes in the tubes. Note the peep-hole in the receiving tube, through which the beam-spot can be watched as the aligning proceeds. Once the spot is partly on the detector, a sent signal can be heard in the output speaker, and final adjustment can be accomplished by putting the microphone on the speaker to get a feedback squeal; the tube alignments are adjusted for maximum squeal.

Although the mailing-tube approach is a satisfactory one, it does not produce a very rugged device. Other designs are worth experimenting with, and will depend on the materials available. If deep and long enough cigar boxes were available, for instance (the lenses must be about 4" from the light bulb and detector), the two lenses could be mounted permanently in holes in one wall, and the bulb and detector mounted on movable micrometer-type carriages inside the box. The detector, though, must be shielded from the direct light of the bulb by some type of separation. On the other hand, if a Fresnel lens is used for maximum range, it will be necessary to separate the sending and receiving lenses enough that the Fresnel lens for the receiver does not obscure the sending lens. It is helpful to mount a small red reflector-button, like those used on bicycles, on the front of the apparatus (near the receiving lens, or right on the center of the Fresnel lens if it is used), to enable the sender to see clearly (in the dark) when his beam is on the other man's receiver.

Whatever lens-mounting design is used, it is essential that this optical part of the system (including the sending bulb and photocell detector) be completed during the first day. This will make it possible for the instructors to get the optics aligned that evening (if they work fast), so the sets can be used the next day as soon as the amplifier is built.

The transmitter amplifier circuit is this:



It is designed to be operated by two D-cells in series (different from those in the receiving circuit), and it is essential that the penlight bulb used be the 222 which is a 3V bulb. The 1M pot is to control the brightness of the bulb: full brightness is necessary for aiming, but it must be turned down to achieve maximum modulation of the audio signal. The correct brightness is easily found by scraping or tapping the mike with a thumbnail and adjusting the brightness for "maximum blinking". The optimum position should be marked. (If you want to be fancier, use a cheap 1/4 watt trimmer pot (Newark 60F2226, 39¢) and leave it set for maximum modulation (dim bulb). Add a SPST slide switch (Newark 57F816, 20¢) which, when closed, shorts out the transistor directly above the bulb (but not the 3.9 Ω limiting resistor in series with it) to give maximum brightness for aiming. The trimmer pot may need occasional adjusting as the batteries run down).

The other trimmer pot is intended to maximize the performance of the microphone, which it will do when set equal to the (average) resistance of the mike. This setting is best found by actually talking into the mike and setting the pot for maximum audio output from the bulb, or by scratching with a thumbnail, as above. The 500 Ω trimmer was chosen to match the Olson carbon-grain mike, which has a resistance of about 300 Ω. If another mike is substituted, a different trimmer may be needed.

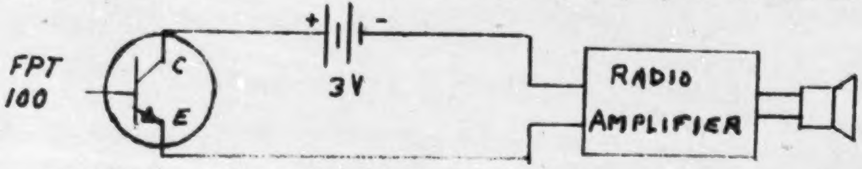
The circuit can conveniently be built on a piece of perf-board (vectorboard) about 3 5/8" x 1 5/8" (cut a standard 3 5/8" x 6 7/8" board into four pieces), which fits nicely into a cigar box.

The transistors shown were chosen because they are readily available and low priced. The first-stage transistor, 2N1307, is a Ge PNP switching type with a low power rating (P_d=150 mW) but relatively high current gain (h_{FE} = 60 to 300). The output transistor, 2N3053, is a Si NPN audio frequency type with considerably higher power (P_d=1 W) and equally high gain. If not available, 2N1711 (which has slightly higher gain) can be substituted, but is 30¢ or so higher in price.

Still another, and cheaper, alternative, is to reverse the battery polarity and use an NPN for the first stage and a PNP for the output. The 2N3053 is fine for the first stage. The 2N1307 does not have enough power-handling capacity to be used in the second stage (P_d of 300 mW or better is necessary), but if you have a transistor tester available, a very attractive possibility is the PNP which Olson sells as Tr-25, at 12/$1.00. Only about 2/3 of them will have sufficient gain (and sufficiently low leakage), but if you can sort out the good ones, they will cost only about 15¢ apiece. All these transistors are in a TO-5 case, and should definitely be used in sockets rather than letting the boys solder on the leads.

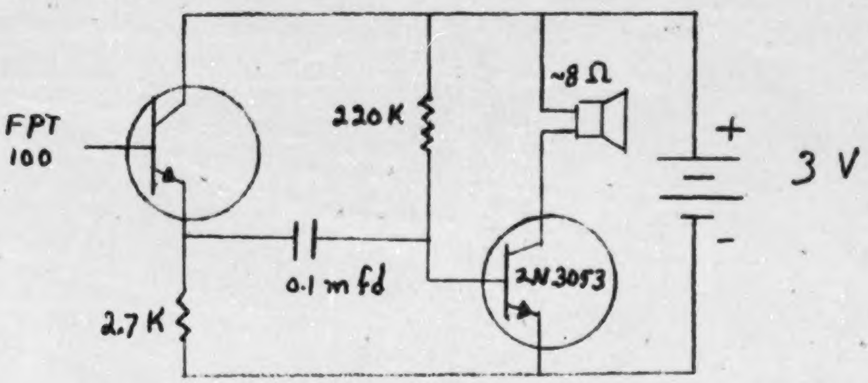
The mike should be mounted on a piece of styrofoam or wooden slat, with the push-button switch mounted on its side as a "push to talk" switch. (If this BA switch is unavailable, Newark has inexpensive push-button switches, one of which is #23F359, for 43¢). The circuit is drawing current from the batteries only when this switch is on.

The receiving photocell is an NPN photo-transistor, FPT-100, obtainable only from Semiconductor Specialists, P. O. Box 66125, O'Hare Airport, Chicago, Illinois 60666 (Tel. (312) 279-1000), for about $1.25. It is much more sensitive than the CdS photo-resistors, but has the disadvantage that the light-sensitive element is extremely tiny (smaller than a pinhead), so that if the incoming beam is focussed down to a spot this size, the aiming of the device becomes extremely critical. This is why the outgoing and incoming beams must be so accurately parallel. The FPT-100 is simply used as a diode; the base terminal is unused, and may be snipped off to keep it out of trouble. The simplest receiver amplifier to use with this photo-transistor is the audio amplifier of the transistor radio, which also has its own speaker and volume control. Simply put the FPT-100 in series with 2 D-cells (3V; it is NPN so the emitter must be negative and collector positive) and the transistor



radio amplifier input wires. Usually one polarity works better than the other for the radio. Because of the external 3V battery, current will leak through the radio even when it is turned off, so it should be disconnected when not in use; a pair of 1/2" round-head stove bolts protruding through the case of the device make convenient terminals to clip the radio to, provided the signal is loud enough to hear from a distance. If it is faint, provide 2' of speaker cable to clip to, so the radio can be held up to the ear.

Alternatively, the following 1-transistor amplifier is readily built:



In this case no extra voltage need be supplied to the FPT-100. The batteries for the receiver should in any case be different from those for the transmitter.

Building either circuit is a major undertaking for the boys, and is best handled by having them all work around one large table if possible. They can then all proceed together, soldering in one component at a time, and having it checked by an instructor before proceeding to the next one.

When two boys have a pair of units finished, they can easily get them set up and operating over any distance up to 50' or so for practice. It is easiest to see when your beam is "on" your partner's receiver by looking for its reflection from his receiving lens. During the daytime this may be difficult because of other lights reflecting from the lens, but blinking your light on and off (at maximum brightness) with the push-to-talk button provides a simple means of identifying it. If the units are closer than about 25', the excessive brightness of the beams may saturate the photocells and prevent them from supplying a usable audio signal. Try simply aiming a little off-center, or even covering part of either lens.

International Morse Code

Character	International Morse Code	Character	International Morse Code
A	. —	1	. — — — —
B	— . . .	2	. . — — —
C	— . — .	3	. . . — —
D	— . .	4	. . . . —
E	.	5	. . . . .
F	. . — .	6	— . . . .
G	— — .	7	— — . . .
H	. . . .	8	— — — . .
I	. .	9	— — — — .
J	. — — —	0	— — — — —
K	— . —	.	. — . — . —
L	. — . .	;	— . — . — .
M	— —	,	— — . . — —
N	— .	:	— — — . . .
O	— — —	?	. . — — . .
P	. — — .	,	. — — — — .
Q	— — . —	_	— . . . . —
R	. — .	/	— . . — .
S	. . .	"	. — . . — .
T	—	-	. . — — . —
U	. — —	=	— . . . —
V	. . . —	Error	. . . .
W	. — —	End of Message	. — . — .
X	— . . —	End of Work	. . . — . —
Y	— . — —		
Z	— — . .		

Equipment Budget Estimate

Because of constantly changing prices, it is difficult to give an accurate estimate of the cost of supplies for the program. The following figures are based on 1969 prices, and an assumed class of 20 boys who build all of the projects. Depending on how much can be borrowed, etc., the total equipment cost including shipping expenses is estimated at $1820 to $2195.

	Cost
A. General Expenses	
Equipment listed on p. 9 (Miscellaneous)	$ 40.
p. 10 (Tools & extension cords)	74.
p. 11 (Tools)	(100)
pp. 11-12 (Miscellaneous)	70.
p. 14 (Storage boxes & locks)	60.
	$244.
	($344.)
B. General Supplies for projects on days 1, 5, 6, 10, 12, 13, 15	$ 55.
C. 23 Tool Boxes and their Tools ($13.50/boy)	$310.50
D. 1. Supplies for the 17 days (23 units for 20 boys)	
Case A ($41.25/boy)	$950.
Case B ($44.25/boy)	$1020.
Case C ($46.25/boy)	$1062.
Case D ($53.65/boy)	$1225.
2. Lumber for the projects (if purchased)	$ 60.

E. Sales tax and Shipping charges (1000 miles)		$ 200.
Total:	Case A	$1820.
	Case B	$1890.
	Case C	$1932.
	Case D	$2095.

This does not include the tools listed on p. 11, which it should be possible to borrow. If they must be purchased, add $100.

The differences between the various "Cases" are these. On the 3rd day it may be necessary to purchase a $3.00 battery for each boy, on the 15th day a $2.00 relay, and on the 16th day the parts for a second intercom station. If none of these are purchased, the total cost corresponds to Case A. Successively adding the battery, relay and intercom station give Cases B, C and D. In no case has an extra $2.05 been added (17th day) for a receiver-amplifier for the intercom, on the assumption that the transistor-radio amplifier will suffice.

Note that the expenses quoted are based on the purchase of 23 units for 20 boys, to allow for breakage and defective parts.

The detailed list of expenses for supplies for one boy is as follows (Case A):

1st Day	$2.88	9th Day	$1.78
2nd Day	.52	10th Day & 11th Day	2.66
3rd Day	2.48		
4th Day	1.29	12th Day	7.20
5th Day	2.67	13th Day	.85
6th Day	3.35	14th Day	2.58
7th Day	1.01	15th Day	3.00
8th Day	1.58	16th Day & 17th Day	7.40
			$41.25

This averages $2.42 per day.

MAYAN STONE CARVING

The illustration on the back cover depicts one of the finest pieces of pre-Columbian stone sculpture in the Western hemisphere. It is a "rubbing" made from the sacred Tablet of the Temple of the Foliated Cross, at Palenque in the jungles of southern Mexico, and was carved by Mayan artisans in 692 AD.

The Mayans, a Central American Indian group still 2 million strong, are noted for their remarkable early achievements in writing, mathematics and astronomy. By the beginning of the Christian era they had developed an elegant system of writing (still largely undeciphered), which is represented in this illustration by vertical columns of hieroglyphs. Their astronomical and calendrical records, which are also nearly this old, were written in a base-20 number system considerably more compact and imaginative than the Roman numerals then being used in the Mediterranean world. It is a "bar-and-dot" system, in which a vertical bar represents five and a dot represents one. Several of these numbers can be seen on the Tablet, such as the 8 and 3 immediately behind the shoulder of the left priest, and the 14 to the left of that.

The Mayans are justly famous for the precision of their astronomical observations. Merely by watching the motion of the rising and setting of Venus along the horizon (without the aid of lenses or any other optical instruments), they were able to measure the length of its year to an accuracy of one part in 30,000. By similar observations on the sun, they measured the length of the earth-year to one part in a million. The error in this measurement is slightly less than the error in our presently-used Gregorian year, and 40 times smaller than the error in the old Julian year, which was in use in Europe at the time the Mayan measurement was made.

The Tablet is 6' high by 8' long. It depicts a stylized maize plant ("cross") surmounted by the sacred quetzal bird, whose iridescent green tail plumes were used extensively in the ceremonial headgear of Mayan priests.